CLIMATE
How Feedbacks Could Speed Warming

NEUROSCIENCE
Growing an Eye in the Lab

BIOLOGY
How Do Genes for Autism Spread?

SCIENTIFIC AMERICAN

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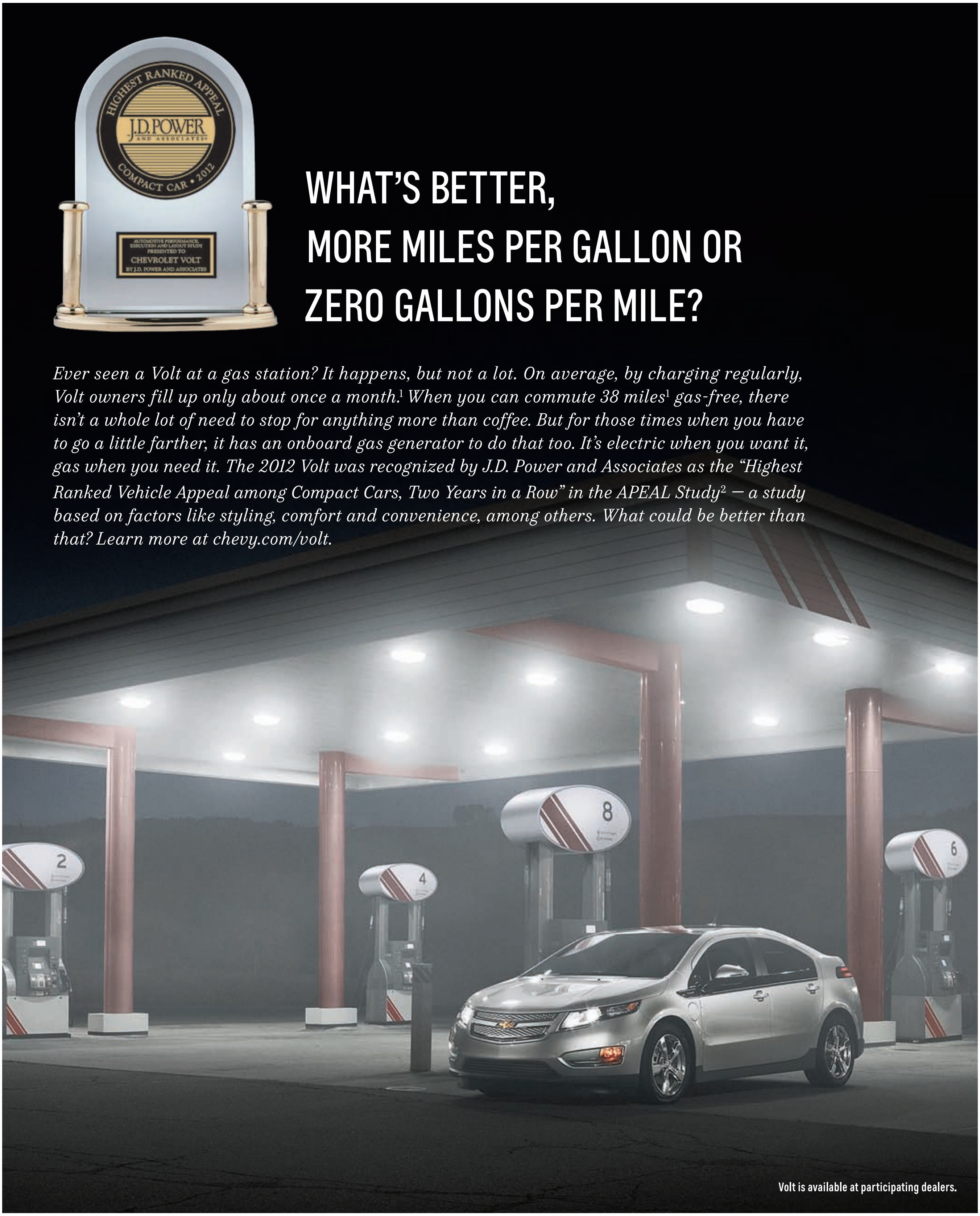
NOVEMBER 2012

The Inner Life of Quarks

Science aims to look inside the smallest bits of matter

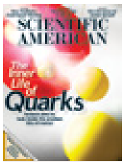
SPECIAL ELECTION REPORT
OBAMA & ROMNEY Answer 14 Science Questions



1 Based on EPA-estimated 98 MPGe (electric); 35 MPG city/40 highway (gas). Actual mileage may vary. **2** The Chevrolet Volt received the highest numerical score among compact cars in the proprietary J.D. Power and Associates 2011 and 2012 Automotive Performance, Execution and Layout (APEAL) Study.[SM] Study based on responses from 74,759 new-vehicle owners, measuring 233 models and measures opinions after 90 days of ownership. Proprietary study results are based on experiences and perceptions of owners surveyed February–May 2012. Your experiences may vary. Visit jdpower.com.

2013 Chevrolet Volt. Chevy Runs Deep

ON THE COVER



The Standard Model of particle physics holds that quarks (the constituents of protons and neutrons) and leptons (such as the electron) are indivisible. Yet some findings suggest that quarks and leptons actually contain still tinier building blocks, known as preons. If preons exist, they will lead to discoveries of phenomena scientists have yet to imagine. Photograph by Craig Cutler.

SCIENTIFIC AMERICAN

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FRANS LANTING

FEATURES

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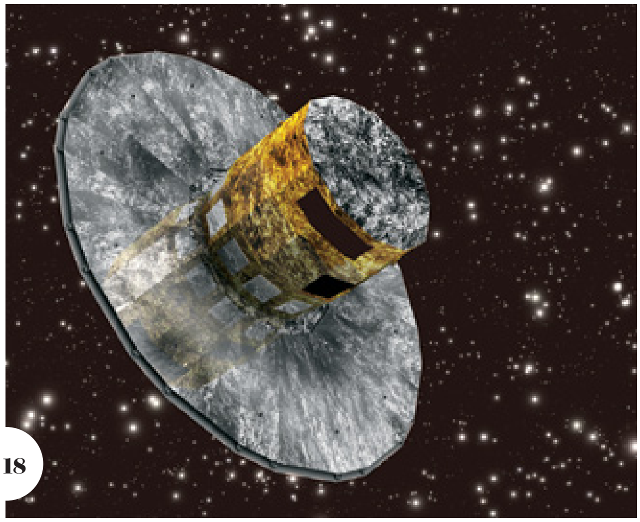

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

Election 2012: The Science Perspective
As the U.S. presidential campaign kicks into high gear, we provide news and analysis about the candidates' statements and track records on science, technology, the environment and health care.
Go to www.ScientificAmerican.com/nov2012/campaign

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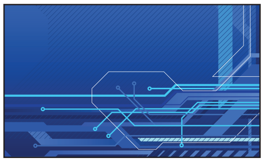


NANOSCIENCE

Chris Sorensen, Ph.D.

Fire, Fractals and the Divine Proportion

Physicist Chris Sorenson discusses the mysteries, beauties, and curiosities of soot. Take an unlikely journey of discovery of soot to find fractal structures with non-Euclidian dimensionality, networks that tenuously span space and commonalities among spirals, sunflowers and soot. Gain an appreciation for the unity of Nature, and the profound lessons in the commonplace as well as the sublime through soot!

Light Scattering

Take a *particle* physics perspective and ask: how do particles scatter light and why does light scatter in the first place? What are the effects of scattering on the polarization? How do rainbows, glories and sundogs work? How do light scattering and absorption effect the environment? Get the latest on scattering and see your universe in a new light.

Nanoparticles: The Technology.

Nanoscience has spawned a significant nanotechnology. Explore new nanomaterials such as self cleaning surfaces and fibers stronger yet lighter than steel. Then we'll do some informed daydreaming about far reaching possibilities like nanobots that could take a "fantastic voyage" inside your body or stealth materials for the invisible man. Enjoy reality science fiction at its best!

Nanoparticles: The Science.

What makes "nano" so special? Why does nano hold such great promise? Take a look at the clever chemistry that creates the nanoparticle building blocks of the new nanomaterials. Find out why physical properties of nanoparticles differ from larger particles. When this session is over, you'll understand why small can be better.

ASTROBIOLOGY

Speaker: Seth Shostak, Ph.D.

Hunting for Life Beyond Earth

Is Earth the only planet to sport life? Researchers are hot on the trail of biology beyond Earth, and there's good reason to think that we might find it within a decade or two. How will we find alien biology, and what would it mean to learn that life is not a miracle, but as common as cheap motels?

Finding E.T.

Life might be commonplace, but what about intelligent life? What's being done to find our cosmic confreres, and what are the chances we'll discover them soon? While most people expect that the cosmos is populated with anthropomorphic aliens aka "little gray guys with large eyes and no hair" you'll hear that the truth could be enormously different.

What Happens If We Find the Aliens?

One-third of the public believes that aliens are visiting Earth, pirouetting across the skies in their saucers. Few scientists agree, but researchers may soon discover intelligent beings sharing our part of the galaxy. Could we handle the news? What facts could be gleaned

immediately, and what would be the long-term effects such a discovery would have on us and our institutions, such as religion?

The Entire History of the Universe

Where and when did the cosmos begin, and what's our deep, deep future? The book of Genesis gives only a short description of the birth of the cosmos, but modern science can tell a more complex tale. How did the universe get started, and could there be other universes? And how does it all end, or does it end at all?

SKEPTICISM

Speaker: Michael Shermer, Ph.D.

The Believing Brain: From Ghosts and Gods to Politics and Conspiracies — How We Construct Beliefs and Reinforce Them as Truths

The brain as a "belief engine"? Learn how our brains' pattern-recognition and confirmation bias help form and reinforce beliefs. Dr. Shermer provides real-world examples of the process from politics, economics, and religion to conspiracy theories, the supernatural, and the paranormal. This discussion will leave you confident that science is the best tool to determine whether beliefs match reality.

Skepticism 101: How to Think Like a Scientist

Harvest decades of insights for skeptical thinking and brush up on critical analysis skills in a lively session that addresses the most mysterious, controversial, and contentious issues in science and skepticism. Learn how to think scientifically and skeptically. You'll see how to be open-minded enough to accept new ideas without being *too* open-minded.

The Science of Good and Evil: The Origins of Morality and How to be Good Without God

Tackle two challenging questions of our age with Michael Shermer: (1) The origins of morality and (2) the foundations of ethics. Dr. Shermer peels back the inner layers covering our core being to reveal complex human motives — good and evil. Gain an understanding of the evolutionary and cultural underpinnings of morality and ethics and how these motives came into being.

The Mind of the Market: Compassionate Apes, Competitive Humans, and Other Lessons from Evolutionary Economics

How did we evolve from ancient hunter-gatherers to modern consumer-traders? Why are people so irrational when it comes to money and business? Michael Shermer argues that evolution provides an answer to both of these questions through the new science of evolutionary economics. Learn how evolution and economics are both examples of complex adaptive systems. Get your evolutionary economics tools together.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

IGUAZU FALLS

March 5–7, 2013 — Surround yourself with 260 degrees of 240 foot-high walls of water at Iguazu Falls. Straddling the Argentinian-Brazilian border, Iguazu Falls is split into about 270 discrete falls and at peak flow has a surface area of 1.3 million square feet. (By comparison, Niagara Falls has a surface area of under 600,000 square feet.) Iguazu is famous for its panoramic views and breath-taking vistas of huge sprays of water, lush rainforest, and diverse wildlife.

You'll walk Iguazu National Park's extensive and well-engineered circuit paths over the Falls, go on a boat ride under the Falls, be bowled over by the massiveness and eco-beauty, and take a bazillion pictures.

MACHU PICCHU

February 15–20, 2013 — Scale the Andes and absorb Machu Picchu's aura. Visit this legendary site of the Inca World, draped over the Eastern slopes of the Peruvian, wrapped in mystery. Whether it was an estate for the Inca emperor Pachacuti or a site for astronomical calculations, it captures the imagination. Visit Machu Picchu, and see for yourself the massive polished dry-stone structures, the Intihuatana ("Hitching Post of the Sun"), the Temple of the Sun, and the Room of the Three Windows. Iconic ruins, rich flora and fauna, and incomparable views await your eye (and your lens).

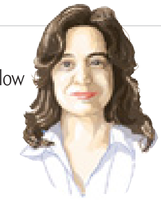
EASTER ISLAND

Febrruary 16–20, 2013 — The moai of Easter Island linger in many a mind's eye, monumental statues gazing inland, away from the South Pacific. Join Bright Horizons on a four-day pre-cruise excursion to explore the mysteries of Rapa Nui. Visit archaeological sites, learn about the complex cultural and natural history of the island, and absorb the ambiance of one of the most remote communities on Earth. Come along on an adventure where archaeology and environment create memories and food for thought.

GALAPAGOS

February 12–20, 2013 — Enter an unearthly natural world in an eight-day pre-cruise excursion to the Galapagos Islands. "See the world in a grain of sand" and hone your knowledge of evolution with your observations in the Galapagos, a self-contained natural history laboratory. We'll tour Santiago, Chile, and straddle the Equator at the "Middle of the World" complex in Quito, Ecuador. Then off to the Galapagos for a four-day expedition on the mv Galapagos Legend. Accompanied by certified naturalists see the incredibly diverse flora and fauna up close. You'll have the opportunity to swim and snorkel, and photograph legendary wildlife and wild landscapes. Join Bright Horizons in the Galapagos for all the intangibles that communing with nature provides.

Mariette DiChristina is editor in chief of *Scientific American.* Follow her on Twitter @mdichristina



Of Quarks and (Presidential) Men

THREE QUARKS FOR MUSTER MARK!
Sure he hasn't got much of a bark
And sure any he has it's all beside the mark.
—James Joyce, *Finnegans Wake*

As he later explained in his 1995 book *The Quark and the Jaguar,* physicist Murray Gell-Mann had the sound of his theorized particle in mind before discovering the spelling he would eventually adopt from a book James Joyce published in 1939. "The number three fitted perfectly the way quarks occur in nature," Gell-Mann wrote, referring to how three quarks make up a proton, itself a component, along with the electron and neutron, of atoms. Although George Zweig, who also theorized this fundamental particle in 1964, preferred the term "ace," quark eventually stuck.

Not so, perhaps, the quark's shared preeminence with the lepton as the most fundamental component of matter. Tantalizing hints in various experiments point to still smaller constituents, dubbed preons, in the particle zoo known to physics. You will learn from "The Inner Life of Quarks," by Don Lincoln, beginning on page 36, that each quark could, in turn, be made of three preons—or perhaps five, depending on which theory you prefer. By 2014 or 2015, after successive upgrades to CERN's Large Hadron Collider near Geneva, scientists hope to find out.

Mysteries drive a lot of science, but we prefer our policy leaders' intentions to be clear. That—and an evidence-based belief that the support of research and innovation has powered humanity's current levels of prosperity—is why *Scientific American* is serving as media partner for an important public discussion.

We worked with ScienceDebate.org and a host of the nation's preeminent scientific organizations, such as the American Association for the Advancement of Science, to secure answers to 14 top scientific questions from presidential candidates Mitt Romney and Barack Obama. You can read their full answers at www.ScientificAmerican.com/article.cfm?id=obama-romney-science-debate. (We also sent a subset of the questions to legislators who have key roles in science policy.)

See our Science Agenda "Future Jobs Depend on a Science-Based Economy," on page 12, for a further discussion of the economic importance of science and turn to "America's Science Problem," by science writer Shawn Lawrence Otto, starting on page 62, to learn about a troubling issue that could impede our nation's progress and to see a report on how well the candidates answered the questions. We hope you find the results as useful as they are thought-provoking. SA

Illustration by Nick Higgins


6,000 ft
Thin salt or absent?
Main Well
12,000 ft
Seismic line
Sand
Marl
New Well?
Miocene
Active Fault?
Oil
18,000 ft
Sandstone
Salt Diapir
Salt
Oil
Carbonate
Shale
24,000 ft
Oil
Sandstone
Paleogene
Shale
RIM syncline?
30,000 ft
19,000 PSI
230°F

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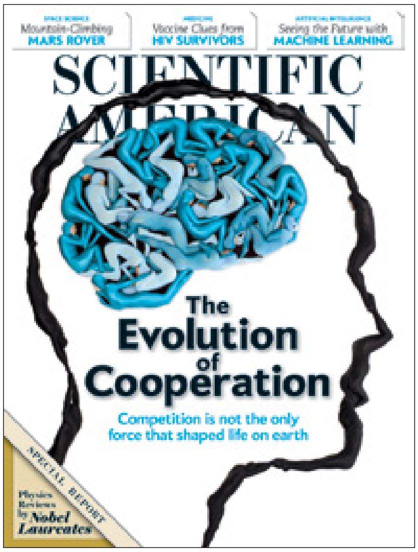

July 2012

"False positive results for many diseases screened in newborns bring unnecessary and prolonged anxiety and sorrow."

ROBERT O. FISCH *UNIVERSITY OF MINNESOTA*

PRIZEWINNING PILGRIMS

The chart of Nobel Prize winners' national affiliations in "Medal Migrations" [Graphic Science] shows the majority of winners as coming from the U.S. Yet how many of those with a U.S. affiliation were born and perhaps educated in other countries only to eventually migrate to the U.S.? And how much of this work was actually done while the prizewinner lived elsewhere? I'm proud to be an American, but I also know that the U.S. is a melting pot.

Eric Pittelkau
Springfield, Va.

MELTING MIX-UP

"Witness to an Antarctic Meltdown," by Douglas Fox, describes ice in Antarctica as disappearing. Yet data from the National Snow and Ice Data Center (NSIDC) show that the Antarctic is *gaining* sea ice, not losing it: http://nsidc.org/data/seaice_index/archives/index.html.

Denny J.
McMinnville, Ore.

FOX REPLIES: The article is about glacial ice. It is easy to confuse sea ice with floating glacial ice, but the distinction is extremely important. Sea ice (discussed on the NSIDC Web page) is very thin, usually around one to eight feet thick, and is formed by water on the surface of the ocean freezing solid during winter. Glacial ice originates on land. It is formed from snow that accumulates and compacts into ice over thousands of years. In parts of Antarctica, glaciers that form on land actually flow off the edge of the continent and onto the ocean. These floating expanses of glacial ice, called ice shelves, are generally 500 to 1,500 feet thick—far thicker than sea ice.

In contrast to the very small overall upward trend in Antarctic sea ice, ice shelves in the northern Antarctic Peninsula are clearly in decline, with four shelves on the eastern side of the peninsula having collapsed in the past 30 years in addition to another two shelves on the western side. Ice shelves along the Amundsen Sea coast of West Antarctica are also retreating.

Whereas sea ice bears little relevance to sea-level rise, ice shelves appear to be extremely important to it. Observations in the Antarctic Peninsula reveal that ice shelves stabilize the glaciers flowing into them from land. When an ice shelf disappears, the glaciers on land behind it accelerate by twofold to ninefold—they spill their ice into the ocean far more quickly, and that ice contributes to sea-level rise. A wide range of satellite and airborne sensing technologies, including gravimetry and laser altimetry, confirm that Antarctica's ice sheets are currently shrinking by 100 billion to 150 billion tons of ice a year.

MEANING OF A LAUGH

Jesse Bering appears to have overlooked an important alternative to Diana Szameitat's interpretation of schadenfreude laughter as a "precise ... tool to dominate the listener" in "The Rat That Laughed." Is it not tenable that when laughing overtly at someone who has "slipped in dog poo," the laugher is exhibiting empathy toward the unfortunate member of his group in that he is reassuring him by his laughter that the incident is not a disaster? If the observer had drawn away, exhibiting distaste and shock, the contaminated one would feel that his social territory was severely abraded and his membership in the group was threatened. That is, the laugher was *involuntarily* demonstrating group cooperation, not domination of the individual.

Richard Bartholomew
Melbourne, Australia

The last sentence in Bering's article—"If only dead pigs weren't so spectacularly delicious"—was incredibly jarring in comparison to his obvious connection and empathy with animals. The idea that such an intelligent, compassionate person would put his taste buds ahead of any consideration of the obscene abuse and suffering of pigs raised and slaughtered for human consumption is disappointing.

Jean Bettanny
Port Townsend, Wash.

FLIGHT RISK

Rather than focusing on the Transportation Security Administration's genuine failings in his column entitled "Technology That Doesn't Fly" [TechnoFiles], David Pogue cries foul because he is too often inconvenienced when flying. When hearing that Pogue must turn off his e-book reader during takeoffs and landings, all I can say is: "Oh, the humanity."

Justice Billings Learned Hand developed a calculus for determining negligence: when the burden of preventing an injury is less than the probability of the injury times its severity, then it is negligent to not attempt to prevent it.

If, as Pogue concedes, "some devices emit signals that could theoretically affect an aircraft's electronics," it would thus be gross negligence to allow them.

Thomas A. Sheehan
Prairie Village, Kan.

HIV CONTROL

In "Secrets of the HIV Controllers," Bruce D. Walker mentions that Bob Massie, whose immune system has been able to fend off HIV, has had a liver transplant. If he thus needs to take immunosuppressive drugs, will these present a threat to his helper T cells and their control of his HIV?

Charles Capwell
via e-mail

WALKER REPLIES: Massie started on anti-HIV medications to ensure that the immunosuppressive drugs would not compromise his ability to control HIV.

SCREENING'S SIDE EFFECTS

Ariel Bleicher brings up an important point about neonatal testing for various diseases in "Perils of Newborn Screening" [The Science of Health]. Placing too much importance on early recognition of diseases that cannot yet be treated is not the only problem. The extremely high incidence of so-called false positive results for many diseases creates not only a great financial burden for society but also brings unnecessary and prolonged anxiety and sorrow.

Robert O. Fisch
Professor emeritus
University of Minnesota

ARACHNID AVIATION

The description of spiders using silk formed into balloons to travel on air currents in "How Spiders 'Balloon,'" by Anna Kuchment [Advances], reminded me of when my husband and I were at about 3,500 feet in our light plane and suddenly found ourselves flying through spider silk! The strands were fairly thick and white and very visible even though we were cruising at about 125 mph.

Deborah King
Willis, Tex.

RELIGION AND REASON

It is surprising to see how "scientists" try to relegate people into superior or inferior categories when it comes to God, such as in the research reported in Daisy Grewal's "How Critical Thinkers Lose Their Faith in God" [Advances]. In this case, those who believe in God are described as tending to rely on "intuitive" rather than "analytic" thinking, which is simplistic to say the least. Offhand, the name "Albert Einstein" should put this theory where it belongs: into the wastebin of history.

Douglas Berman
via e-mail

ERRATUM

"The Motherhood Gap," by Melinda Wenner Moyer [Advances, June 2012], gives an incorrect affiliation for Adam Maltese. He is at Indiana University Bloomington.

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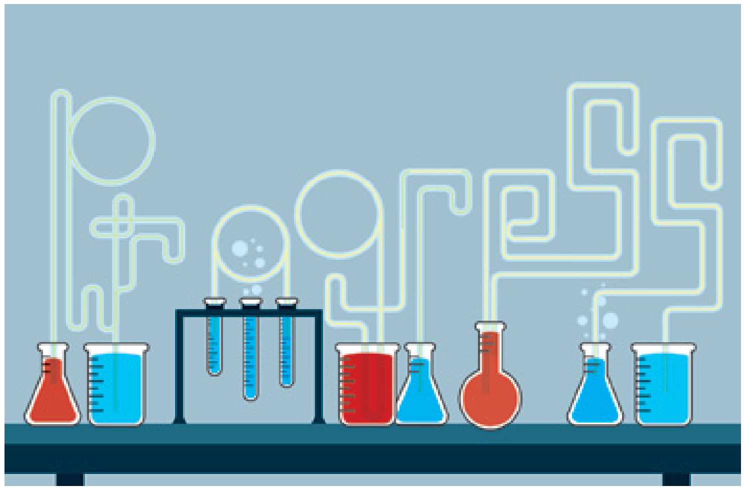
Future Jobs Depend on a Science-Based Economy

The next administration must prime the true growth engine



The 2012 presidential election will be won by the candidate who can convince voters that he has the vision to lift the nation out of the economic doldrums. The economy is the right topic, but the discussion neglects the true driver of the country's prosperity: scientific and technological enterprise. Half of the U.S. economic growth since World War II has come from advances in science and technology. To neglect that power—and the government's role in priming the pump—would be foolish.

The auto industry is a case in point. President Barack Obama makes much out of having rescued Detroit's carmakers from bankruptcy. This achievement won't hold up, however, unless the thousands of small auto-parts manufacturers down the supply chain stay globally competitive. One way to help them would be to foster initiatives like the National Digital Engineering and Manufacturing Consortium, which is providing independent manufacturers potent information technology at Purdue University and the Ohio Supercomputer Center. By harnessing this science and technology strength, we can generate a competitive advantage for small businesses.

President Obama and Governor Mitt Romney ought to be talking about how to use programs like this to bring about the kind of success that Germany has achieved. The German government encourages a close partnership between technical universities and industrial manufacturers; it supports centers where scientists and engineers pursue fundamental research in close proximity to industrial colleagues investigating more applied technologies. German battery makers, for instance, work with technical universities on nanotechnology, while textile makers contribute to research in carbon fibers for composite fabrics. Could there be a grander vision for harnessing U.S. research talent in this way? On this, both candidates have been silent.

Research can also advance other strategic national goals, such as energy security. For instance, the U.S. Department of Energy funded and helped to develop the shale-cracking techniques that have released the country's current surplus of natural gas. And no nuclear reactor has ever been built in this country without financial and scientific support from all levels of government.

The next administration could play a large role in developing novel nuclear reactors and cheap solar power, among other technologies. Yet on this issue the candidates differ markedly, according to their responses to 14 science questions posed by *Scientific American* and ScienceDebate.org [see "America's Science Problem," on page 62]. While Obama touts the $90 billion in federal investments in clean energy research made on his watch, Romney repudiates this "green energy agenda."

His thinking is shortsighted. The bankruptcy of solar panel maker Solyndra in 2011, which critics have used to argue against government support of energy research, instead shows why such investment is so important: experimental projects always carry a high risk of failure, which is why commercial firms are reluctant to undertake them. Yet without them, innovation will slow. The DOE's Advanced Research Projects Agency–Energy funds ideas that may sound like science fiction to some—genetically modifying microbes to produce fuel, for example. History shows that such bold efforts will yield the beginnings of new industries. In 1962, for example, a researcher envisioned a fanciful "Galactic Network" that would connect distant computers, inspiring the Pentagon project that eventually became the Internet.

A high-tech economy needs the best scientists and engineers, yet in science and math, U.S. students are middling. The Obama administration has had some success by tying grants for K–12 schools to Common Core math standards, but neither candidate has come out in support of the Next Generation Science Standards recommended by the National Research Council.

With looming unemployment and debt, such concerns may not seem urgent. Yet unless we invest in an economy built on scientific and technological skills, we will only be papering over our economic troubles. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2012

Illustration by Jason Arias

Evan Charney is associate professor of public policy and political science at the Sanford School of Public Policy at Duke University.

William English is a lab research fellow at the Edmond J. Safra Center for Ethics at Harvard University.

The Voting Gene

When it comes to complex behaviors, gene variants don't count for much

Dozens of studies in the past few years have linked single genes to whether a person is liberal or conservative, has a strong party affiliation or is likely to vote reguarly. The discipline of "geno-politics" has grabbed headlines as a result, but is the claim that a few genes influence political views and actions legitimate?

We don't think so. The kinds of studies that have produced many of the findings we question involve searching for connections between behavior and gene variants that occur frequently in the population. Most of the 20,000 to 25,000 human genes come in hundreds or thousands of common variations, which often consist of slight differences in a gene's sequence of DNA code letters or in repeats of a particular segment. For the most part, scientists do not know what effect, if any, these common variants, known as polymorphisms, have on the functioning of the proteins they encode. Genes predict certain well-defined physiological diseases—such as hereditary breast cancer and the risk of developing Alzheimer's disease—but when it comes to complex human behaviors such as voting, the link is tenuous at best.

One of the most prominent papers showing a link between a few polymorphisms and political behavior was published by James Fowler and Christopher Dawes in 2008 in the *Journal of Politics*. They concluded that people who possess certain variants of a gene called *MAOA* are more likely to vote than those who do not and that people with a particular variant of a gene known as *5-HTT* who regularly attend religious services are also more likely to vote. We do not believe that these conclusions are right.

Like most claims that a specific gene predicts variations in a particular behavior, the findings were based on what is known as a candidate gene association study. Instead of surveying all the genes in the human genome for possible associations with a given trait, such studies look for potential links between polymorphisms for one or two candidate genes and a specific trait. This type of study can be a relatively inexpensive way to conduct research because it usually depends on large databases of information that already exist, but it can lead researchers astray.

We identified two major problems with the study of Fowler and Dawes. First, they misclassified the genes they were studying in a way that amplified the statistical significance of their findings. Second, their methods fell short of adequately taking into account population stratification, in which the frequency of polymorphisms varies from one ethnic population to another as a result of unique ancestral patterns of migration and mating practices. (This is a common problem in the field.) When we analyzed the different ethnic groups in detail, we found inconsistencies. For instance, in the case of Asians, Native Americans and nonwhite Hispanics, we saw the opposite trend—toward less voting.

Yet we have more fundamental issues with these kinds of studies. The same polymorphisms of these same two genes that have been tied to voting are also said to predict variation in other behavioral and physical traits—irritable bowel syndrome, schizophrenia and premature ejaculation. Such broad findings beggar belief. The idea that a pair of genes could be responsible for so many disparate behaviors is biologically implausible.

Recent research provides growing evidence that genetic influences on human behavior involve thousands of different genes, which influence one another and the environment in intricate ways. Differences in aggression among fruit flies, to take just one example, entails the activity of more than 4,000 genes. The chance that any complex human behavior—such as voting—might have one or two major predisposing genes is practically zero. SA

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Photograph by Dan Saelinger

NEUROSCIENCE

The Autism Pill

A new crop of drugs aim, for the first time, at the core symptoms of this disorder

Until now, attempts at treating autism have been limited to drugs that target peripheral symptoms such as anxiety, aggression and repetitive behaviors. But researchers hope that data from a crop of new drugs in development will allow them, for the first time, to treat an underlying mechanism of the condition, potentially helping those with autism to communicate.

The majority of autism cases are idiopathic, meaning that researchers have yet to understand their cause. But some animal studies of autism have pointed to signaling problems in the brain. Targeting those signaling problems, some researchers think, may ameliorate autism symptoms once thought to be intractable.

Researchers have gleaned some of this information by studying a handful of diseases caused by single-gene glitches that can result in autism. Such disorders account for about 15 to 20 percent of autism cases, says Geraldine Dawson, scientific director of Autism Speaks. In fragile X, which causes autism in a significant number of cases, the points of contact between neurons contain too much glutamate, a chemical messenger that transmits excitatory signals. “There’s an optimal level of activation” in the brain, and this equilibrium is disrupted in fragile X, explains Randall L. Carpenter, co-founder and CEO of Cambridge, Mass.–based biotech firm Seaside Therapeutics. The company is developing drugs that aim to rebalance levels of excitatory and inhibitory messengers, known as neurotransmitters. Hitting that sweet spot may allow the brain to develop the necessary connections for weeding out background noise and focusing on important information, Carpenter says. That, in turn, might allow patients to feel less overwhelmed by sensory stimuli and to have an easier time interacting with others.

Yet do those with idiopathic autism suffer from that same glutamate imbalance? That is what Seaside is working to find out. The company’s most advanced drug, arbaclofen, dampens glutamate activity and has reversed some symptoms in mouse models of fragile X. Data so far also suggest some benefits in humans. “The big question is whether these same drugs can address symptoms in people with idiopathic autism,” Dawson says. Seaside’s study exploring that question is due out later this year. If arbaclofen works in at least some of these individuals, that finding would offer the first evidence that certain cases of idiopathic autism share the same well-studied neurobiological flaws as single-gene permutations of autism. More important, it would show, for the first time, that autism is treatable with drugs. “That will be a watershed moment,” Dawson says.

Still, big questions remain. Thus far, researchers have had little success designing drugs that target glutamate without side effects. And should the drugs work, researchers will still need to determine at what age they would be most beneficial, because autism begins early in development. But the results of Seaside’s trials and those of similar drugs in the pipeline, Dawson says, “are going to be a huge step to understanding what the path to discovery is going to be.” *—Alla Katsnelson*

MARTIN SOEBY *Gallery Stock*

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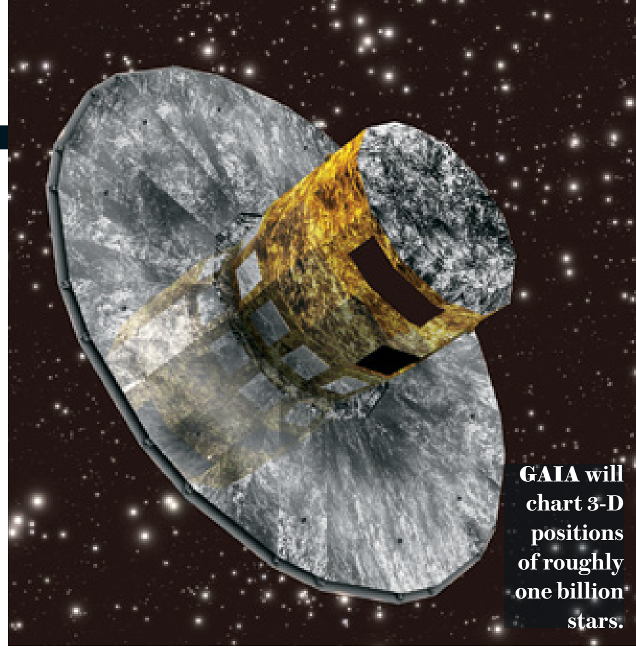
ASTRONOMY

You Are Here

Astronomical surveys are pinpointing our place in the cosmos



GAIA will chart 3-D positions of roughly one billion stars.

Like surveyors charting out a parcel of land by measuring angles, distances and elevations, astronomers have long mapped the positions of celestial objects in the sky.

Those celestial maps are about to see some major revisions. New and upcoming campaigns using ground-based telescopes or spacecraft promise to fill in many new details. Together these projects will catalogue positional information on several billion stars and galaxies, near and far.

By scanning the skies for six years, a next-generation space telescope called Euclid ought to map up to two billion galaxies in three dimensions. The mission, which the European Space Agency (ESA) approved this past June for a 2020 launch, will scan about one third of the sky to measure the positions and distances of galaxies across the universe. The hope is that the distribution of cosmic structure will reveal some hidden clue to the nature of dark energy, the unknown entity driving the accelerating expansion of the universe.

A dramatic upgrade to local celestial cartography should come even sooner from ESA's Gaia spacecraft, which is scheduled to launch next year. After arriving in deep space, well beyond the orbit of the moon, Gaia will map the positions and distances of roughly one billion stars. "The main science goal is to address the issues of our Milky Way—the structure and the dynamics," says Timo Prusti, project scientist for Gaia at ESA.

Meanwhile, back on Earth, many new surveys are now coming online in the Southern Hemisphere, where celestial cartographers can expect to make the greatest impact. In the North, the granddaddy of all astronomical surveys—the Sloan Digital Sky Survey in New Mexico—has already carefully mapped more than one million galaxies in three dimensions, in addition to many other accomplishments.

The telescope most likely to rewrite the books on the southern sky is the Large Synoptic Survey Telescope, or LSST, in Chile. When it comes online around 2022, the LSST—as currently envisioned—will feature an 8.4-meter primary mirror (compared with the Sloan survey's 2.5-meter telescope) and a 3.2-gigapixel digital camera. The mammoth telescope will image the heavens every week to capture transient phenomena such as supernovae and close passages of potentially dangerous asteroids. In the process, it will also mark the three-dimensional location of some four billion galaxies. *—John Matson*

PHYSICS

Scaled Down

A new nanodevice can weigh single molecules in real time

Measuring the masses of tiny objects takes a tiny scale. To that end, researchers from the California Institute of Technology and Leti, an institute at the French Alternative Energies and Atomic Energy Commission, have built a new mass-identifying device with dimensions measuring in the nanometers and microns. The apparatus can determine the masses of individual molecules in real time—the first device of its kind to do so—the researchers reported in a study published in September in *Nature Nanotechnology.* (*Scientific American* is part of Nature Publishing Group.)

The heart of the scale is a beam of silicon just a few hundred nanometers wide that vibrates at two tones simultaneously. (A nanometer is one billionth of a meter.) Tiny arms at either end of the beam convert the resonator's vibrations into an electrical signal via a phenomenon known as the piezoresistive effect. A single molecule landing on the beam is enough to shift the frequency of the two tones downward, changing the electrical resistance of the device's arms in a way that depends on the mass of the particle.

As a demonstration, the researchers performed mass spectrometry—identifying the various particles in a mixture by their masses—on collections of gold nanoparticles five nanometers in diameter, as well as on the antibody molecule immunoglobulin M. As study co-author Michael Roukes, a Caltech physicist, notes, previous resonator devices needed hundreds of identical molecules to make a measurement. "We couldn't actually know, molecule by molecule, what their mass was," he says.

The new, more sensitive version should allow researchers to perform mass spectrometry to identify the various particles within a mixed sample. A mass spectrometer capable of identifying single protein molecules could prove invaluable for proteomics—teasing out the function and structure of different proteins within a cell or tissue. "If we can do it one by one, now we can start looking at arbitrarily complex mixtures of different things," Roukes says. *—John Matson*

COURTESY OF C. CARREAU ESA

COMMENT AT ScientificAmerican.com/nov2012

TECHNOLOGY

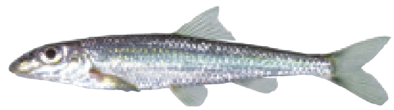
Roaches to the Rescue

Engineers design robo pests to search for earthquake victims

Cockroaches typically elicit revulsion, not relief. Yet what if you were trapped in a collapsed building, and rescuers had sent in a cockroach to find you? A team of researchers has harnessed the cockroach's uncanny survivability in ways that could help humans in the wake of disasters. The scientists direct the insects' movements by sending wireless pulses to the roaches' antennae. Roaches use their antennae as touch sensors, so stimulating one makes a roach think there is an obstacle in its path, and it moves in the opposite direction. "What we do is similar to riding a horse," says Alper Bozkurt of North Carolina State University's department of electrical and computer engineering. Bozkurt and doctoral candidate Tahmid Latif presented their research in August at the 34th Annual International Conference of the IEEE Engineering in Medicine & Biology Society.

The team fitted Madagascar hissing cockroaches with electrical devices that look like backpacks. Each backpack had a printed circuit board with a microcontroller, wireless signal receiver and lithium-ion polymer battery. Tiny stainless-steel electrodes connected the circuit board to the roaches' antennae. The researchers then wirelessly sent electrical impulses to the backpacks' receiver, which stimulated either the left or right antenna. In the future, the roaches might have a tiny camera through which rescue workers could check for survivors. Bozkurt and Latif see their roaches as an alternative to small-scale robots, which are challenging to design. —*Larry Greenemeier*

Illustrations by Thomas Fuchs



ECOLOGY

Dead in the Water

North American freshwater fishes are going extinct at rates that concern scientists

We may not miss the phantom shiner, the thicktail chub, the stumptooth minnow or the harelip sucker, but these freshwater fishes are among 39 species (3.2 percent of North America's freshwater fish population) and 18 subspecies that have vanished from the continent's waters over the past century. By 2050 the tally could reach as high as 86, an extinction rate that is about 877 times higher than normal and that has accelerated in the past 20 years, according to a study in the September issue of *BioScience*. When so many fish disappear in a short period, "you know something's up," says study author Noel M. Burkhead of the U.S. Geological Survey.

Many of the extinct freshwater fishes lived in the Great Lakes region and most likely died off because settlements and cities built on the lakes contributed to pollution, overfishing and the introduction of nonnative species that outcompeted them. As compared with saltwater and terrestrial animals, freshwater species are particularly vulnerable because many depend on small, local water bodies. "The numbers should be a wake-up call that we urgently need to apply freshwater conservation efforts," says Marguerite A. Xenopoulos of Trent University in Ontario, who authored a 2005 study on freshwater fish extinctions but was not involved in the current research.

Scientists are still working to understand what impact these extinctions might have on other populations. Although they understand the dynamics of large ecosystems, ecologists cannot yet "predict what the loss of a certain organism would mean," Burkhead says. These fish are "doing something beneficial. We just don't know what all those benefits are yet." —*Carrie Madren*

COURTESY OF NOEL M. BURKHEAD AND ROBERT E. JENKINS *Virginia Department of Game and Inland Fisheries*

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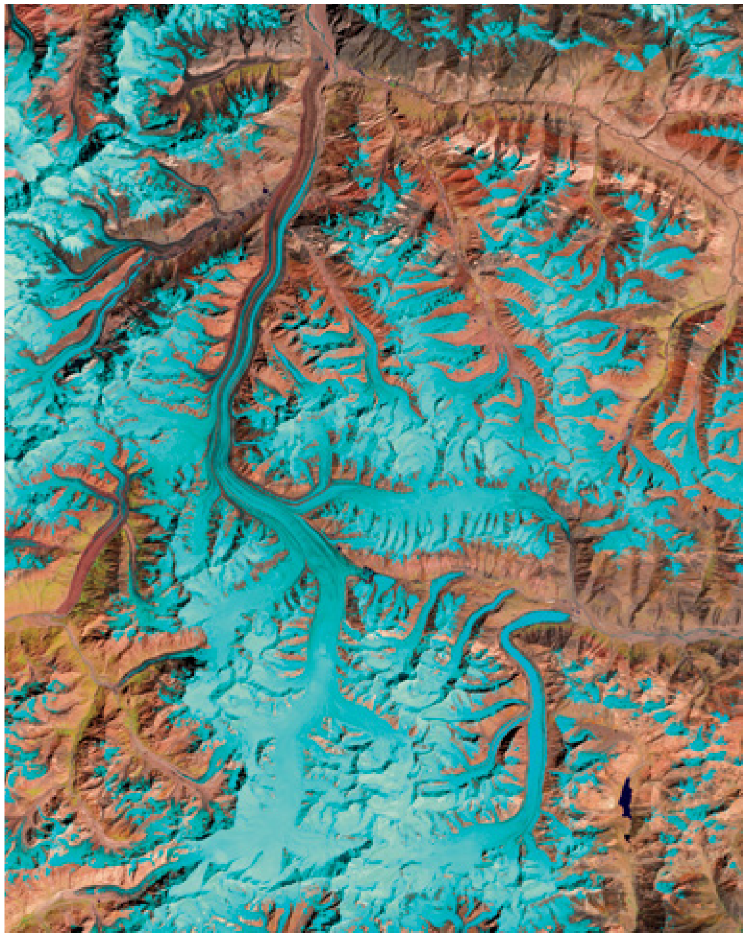


WHAT IS IT?

Fading frost: The world's ice is in retreat. This summer about 97 percent of Greenland's ice sheet melted, and the extent of Arctic sea ice reached an all-time low. In Central Asia's Pamir Mountains, the Fedchenko Glacier, seen in this false-color image, has shrunk 4,600 feet over the past 80 years. The loss of this glacier's snow and ice (*cyan*) may slow down, however. According to research in the September *Nature Climate Change,* precipitation patterns in the area have increased, which may help larger glaciers such as this one stick around a while longer. —*Ann Chin*

COURTESY OF JESSE ALLEN AND ROBERT SIMMON NASA *Earth Observatory*

STAT

18 trillion

Current global energy demand, in watts

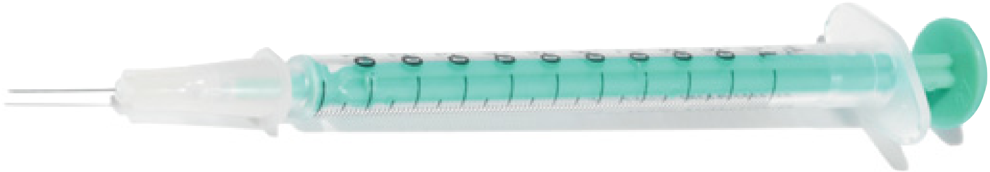
239 billion
The amount of wind energy, in watts, that existing turbines are capable of producing

250 trillion
The amount of power, in watts, that could potentially be extracted from the wind

COMMENT AT ScientificAmerican.com/nov2012

HEALTH

A Shot in the Arm



Health departments have shrunk, raising fears about epidemics

Local and state health departments across the U.S. monitor communities for infectious disease outbreaks, ensure that restaurant food is safe, and provide walk-in immunization and clinics for sexually transmitted diseases. Yet since the financial crisis began in 2007, 40 percent of the nation's health departments have suffered serious budget cuts that have forced them to shed a quarter of their workforce. Many experts fear that these cutbacks are putting the country at risk for epidemics.

Consider Duval County, Florida: it is in the midst of the worst tuberculosis outbreak in the U.S. in 20 years, yet in March, Florida governor Rick Scott signed a bill downsizing the state health department and closing A. G. Holley State Hospital, which specialized in treating tuberculosis patients who were not taking their medications, a practice that spurs drug resistance. (Mike Haridopolos, president of the Florida Senate, has said that the budget helped make the state "more attractive to business owners and entrepreneurs," in part because it did not raise taxes.) "The outbreak is among the very people who were typically candidates for A. G. Holley," says Marc Yacht, former president of the Florida Public Health Association. Some patients were transferred to other hospitals, and the four who were discharged are considered noninfectious, and health workers are checking on them daily, reports the Florida Department of Public Health.

In California, which has more than one fifth of the country's TB cases, recent budget cuts have forced more than a quarter of local health departments to cut basic clinical services and surveillance for the disease. "We're setting ourselves up for a resurgence," says Robert Benjamin, former tuberculosis controller for the Alameda County Public Health Department. The Centers for Disease Control and Prevention estimates that more than 11 million Americans—among them 2.5 million Californians—have latent TB infections that can become active.

Immunization services have also been hit hard. Snohomish County, Washington, is the epicenter of an ongoing pertussis (whooping cough) outbreak that started in March 2011. To curb its spread—pertussis can kill young infants—the county health department recommends vaccinations for kids and adults. Yet in 2009 budget cuts forced the department to halve its immunization clinic hours and to eliminate 30 percent of its full-time staff. Montgomery County, Texas, recently canceled an annual event that provided kids with free or low-cost vaccines—which is a problem, considering that one third of young children in Texas have not received all their recommended vaccinations. The crisis has prompted the Institute of Medicine to hold a meeting in Washington, D.C., to discuss how health departments can continue to provide essential services in the face of dwindling resources.

A lack of awareness about what health departments do contributes to the funding woes. "When departments are doing their jobs well, nothing happens," says Robert Pestronk, executive director of the National Association of County and City Health Officials. Yet, he argues, health departments are as important as police and fire departments. "We may not wear uniforms," says Gary Goldbaum, director of the Snohomish Health District, "but we're also doing lifesaving work."

—Melinda Wenner Moyer

DAVIES AND STARR *Getty Images*

BIOLOGY

Some Don't Like It Hot

Mustard's kick may be a defense mechanism to ward off pests

When you pass the Grey Poupon, you're probably not thinking about nature's defense systems. Recent research, however, has found that the chemical compounds behind mustard's kick help the plant family to deter pests.

Researchers at Duke University, the Max Planck Institute for Chemical Ecology in Jena, Germany, and the University of Illinois at Urbana-Champaign studied the mustard plant species *Boechera stricta.* They looked at two populations of *B. stricta* growing in the Rocky Mountains, one in Montana and another in Colorado. Each population tastes spicy but in a slightly different way, suggesting regionally distinct chemical compositions. The team detailed its findings in the August 31 issue of *Science.*

The investigators first analyzed specimens from the Colorado and Montana populations in the laboratory. Molecular analysis pinpointed three genes, dubbed the *BCMA* family, that code for an enzyme responsible for beginning the production of the compounds that give each variety of mustard its distinctive taste. Depending on which *BCMA* genes are present, the resulting enzyme will produce the distinct flavor of either a Montana or Colorado mustard plant.

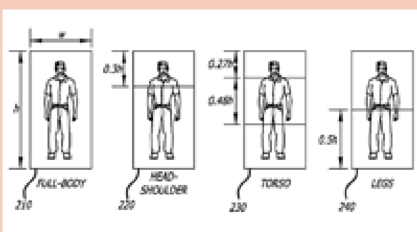
Duke researcher Thomas Mitchell-Olds and his colleagues next planted thousands of Colorado and Montana mustard plants together on field sites in both states. They found that Montana insects stayed away from Montana plants but devoured the Colorado variety. Their aversion suggests that the Montana mustard's spice is specially formulated to deter local pests. It is therefore possible that many generations ago a mutation in the *BCMA* gene created a family of plants with the Montana spice that so successfully deflected bugs that this gene became common in the population.

The Colorado site told a slightly different story. These bugs had a less discerning palate: they consumed the local and foreign mustards with similar gusto. The researchers need to investigate further to understand this difference, but it could suggest that the Colorado environment is more competitive and that ravenous pests there must stomach a spice-induced tummy ache or face starvation.

A third experimental step adds additional nuance to mustard's *BCMA* variation. The researchers engineered *Arabidopsis,* a close relative of *B. stricta,* to express the *BCMA* genes, producing either the Colorado or Montana spice variants. When the researchers exposed their tangy *Arabidopsis* plants to pests, they identified a possible trade-off of *BCMA* variation. Although the spicy compounds deter certain insects and pathogens, they can increase susceptibility to others. With further analysis, the researchers hope to better understand how this trade-off affected the regional evolution of *B. stricta*'s flavor. —*Daisy Yuhas*

PATENT WATCH

Human detection and tracking system: Law-enforcement officials are often stuck scrolling through hours of video in an attempt to catch a suspect, an activity that could be sped up with the right software. Unfortunately, current technology cannot reliably track multiple people or sort individuals from a larger group. Even a shadow can confuse programs—its movements might look like a second person. To build systems that work in more crowded environments, co-inventors Ram Nevatia, a computer scientist at the University of Southern California, and Bo Wu, now an engineer at Google, decided to zero in on body parts.



Patent No. 8,131,011 describes a software system that searches videos for human parts—the head, the torso or legs—and figures out how they fit together. Once the software finds a person in the front of a group, it can detect a second body by the head alone. The software can also track moving individuals by predicting where they might be in subsequent frames of the video. The next step is to tweak the software so that it recognizes activities—a function that could potentially catch a thief. —*Marissa Fessenden*

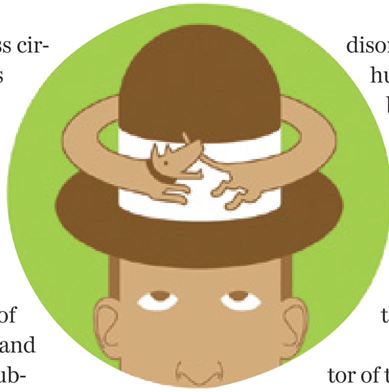
CORBIS (*top*); COURTESY OF U.S. PATENT AND TRADEMARK OFFICE (*bottom*)

COMMENT AT ScientificAmerican.com/nov2012

PSYCHOLOGY

From Tail Chasing to Hand Washing

Researchers believe canine compulsions may be similar to human ones



German shepherds chasing their tail in endless circles and bull terriers snapping at invisible flies appear endearing to some pet owners. Yet researchers say these spontaneous behaviors in dogs may be manifestations of obsessive-compulsive disorder (OCD) and may help shed light on the condition in humans.

"Some of these compulsions are more common in certain breeds, which suggests a genetic factor," says Hannes Lohi, a professor of canine genomics at the University of Helsinki and co-author of a study on canine compulsions published in July in *PLoS ONE.* To learn more about the disorder, Lohi and his colleagues distributed a detailed questionnaire to 368 dog owners in Finland, 150 of which showed no signs of compulsion and served as controls. The researchers also took blood samples from 181 of the canine subjects, which belonged to four breeds: standard and miniature bull terriers, Staffordshire bull terriers and German shepherds.

Researchers said several characteristics of canine compulsive disorder were similar to those of human OCD. Like humans, dogs with compulsive disorders usually began their repetitive behaviors before they reached sexual maturity. Some dogs suffered only a few episodes during their lifetime, whereas others engaged in the behavior for lengthy periods throughout the day. Littermates often had the same behavioral disposition. "There might be a shared biology behind the development of the disease," Lohi says.

Not everyone agrees. Perminder Sachdev, director of the Neuropsychiatric Institute at Prince of Wales Hospital in Randwick, Australia, notes that humans, unlike animals, usually recognize these distressing behaviors and attempt to control them. Tail chasing, he argues, is more akin to stereotyped and repetitive behavior, which is often seen in people with autism. "I think that it is difficult to argue that tail chasing is a true model of OCD," Sachdev says. Lohi, however, plans to check further into dog-human connections in future studies.

—Rachel Nuwer

FIELD NOTES

Fickle Fairies

A biologist on lusty birds and human evolution

Red-backed fairy-wrens are an Australian species of small insectivorous birds. Males and females are socially monogamous—they pair together and stay in a family group. But they are also sexually promiscuous, so a lot of the offspring aren't sired by the male that is raising them at the nest.

When you have all this extra pair mating, there is a lot of competition among the males for females. Sexual competition of this kind can shape sexual signals like plumage, and so it can be an important driver of speciation events. This sort of sexual selection is thought to have been key in human evolution.

In the birds we study, there are two types of males: brightly colored red-and-black ones and drab brown ones. Hormones regulate which path they go on, and social interactions during the prebreeding season appear to regulate hormones. In a relatively high-ranking male, testosterone goes up, and he develops into a bright guy. But if he gets negative social feedback—like receiving little interest from females or aggression from other males—his testosterone goes down, and he develops into a drab guy. The red-and-black males sire a lot more young, and becoming brown makes the best of a bad situation. They are unlikely to be breeders, so they save whatever costs there are of having a bright breeding phenotype. But the plumage change is not permanent. They just wait for another year or two until they are in better condition and then breed as bright males.

Many earlier, simple models in evolution didn't take into account the idea of phenotypic plasticity, such as these temporary plumage changes. We are interested in understanding what the consequences of that plasticity are.

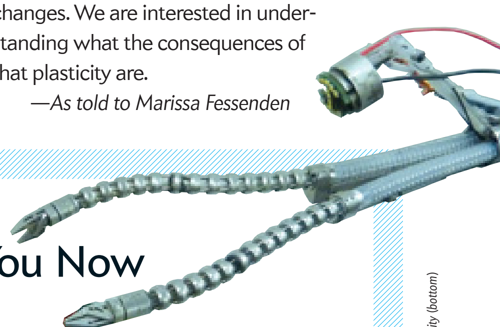
—As told to Marissa Fessenden

PROFILE

NAME
Mike Webster

TITLE
Evolutionary biologist

LOCATION
Cornell Lab of Ornithology Ithaca, N.Y.



SURGERY

The Robot Will See You Now

Laparoscopies with fewer incisions

Modern laparoscopic surgeries may be minimally invasive, but they still require multiple incisions. To make laparoscopies even less intrusive, scientists and surgeons at Columbia University and Vanderbilt University have built a robot that can enter the body through a single 15-millimeter incision or through a natural opening like the mouth. Once inside the body the robot, which has not yet been tested in humans, unfolds like a NASA spaceship, communicates its position through a wire connected to an external computer, and follows instructions to advance, stop, tie sutures and perform other actions. It comes with a camera that tracks the movements of surgical instruments and projects them onto a computer console. Developers say it could perform appendectomies, hysterectomies, some types of kidney surgery, and possibly ear and throat surgery.

The Insertable Robotic Effector Platform (IREP) is entering animal testing this fall and could be available within five years. Until now, no study has offered conclusive proof that robotic surgery trumps traditional laparoscopic techniques, but IREP's developers say it is lighter and cheaper than da Vinci, the leading surgical system. "There is definitely a potential here," says William Lowrance, a robotic surgery expert at the University of Utah, adding that it might offer more dexterity and precision than traditional laparoscopic tools. *—Lina Zeldovich*

MARTIN WILLIS *Minden Pictures* (top); COURTESY OF DENNIS FOWLER AND NABIL SIMAAN *Columbia University* (bottom)

COMMENT AT ScientificAmerican.com/nov2012

MATERIALS

Break More to Break Less

A new kind of hydrogel could open the way to artificial cartilage and other applications

The secret to making something break less is to make it break more—at least at a microscopic level. When something brittle such as glass shatters, the only molecules involved in the breakage are the ones along the surface of the shards; inside individual fragments, the material is virtually unaffected. To reduce brittleness, researchers design materials that distribute stress below the surface, which prevents cracks from propagating and keeps the object from breaking up in the first place.

Zhigang Suo of Harvard University and his collaborators have now applied this principle to a class of materials called hydrogels, which are made up of water and networks of long molecules known as polymers, which act as scaffolding. Suo's hydrogels, which have the consistency of rubber, can stretch to 20 times their original size without breaking. By comparison, a typical rubber band snaps if it is stretched more than sixfold, Suo says. The new material also has remarkable toughness, which, in the technical sense, is the ability to absorb pressure, tension or an impact without breaking. The energy it takes to break this hydrogel is 10 times greater than for similar materials.

Previous hydrogels lacked toughness and often fell apart like tofu. The secret of Suo's hydrogel is that it contains not one polymer scaffolding but two. The first is made of long carbohydrate chains derived from algae. The chains, held together by positively charged calcium ions, pair up like the two sides of a zipper.

A secondary scaffolding consists of a synthetic polymer whose long chains link together in strong bonds. When an impact hits the material, the algae-derived chains unzip and the calcium ions disperse in the water. The secondary network distributes the stress deeper below the cracking surface, so the energy dissipates into a larger volume of the material. Once the stress is removed, the material self-heals because calcium ions, attracted to negatively charged segments in the algae chain, zip the primary network back together.

The new material, though not ready for prime time, shows that hydrogels may be strong enough for applications such as tissue engineering and prosthetics. "Today if your cartilage is damaged, it is very difficult to replace," Suo says. And any artificial replacement would need to be at least as tough as the natural stuff. Suo and his collaborators published their work in the September 6 issue of *Nature*.

The energy it takes to break the new hydrogel is "really impressive," says Hokkaido University's Jian Ping Gong, who in 2003 led the team that first pioneered double-network hydrogels. Gong, however, points out that the self-healing in the new material is not complete and is somewhat slow, taking several hours. To be useful in applications, the material will have to reach 100 percent healing, she says, and do so in a shorter time.

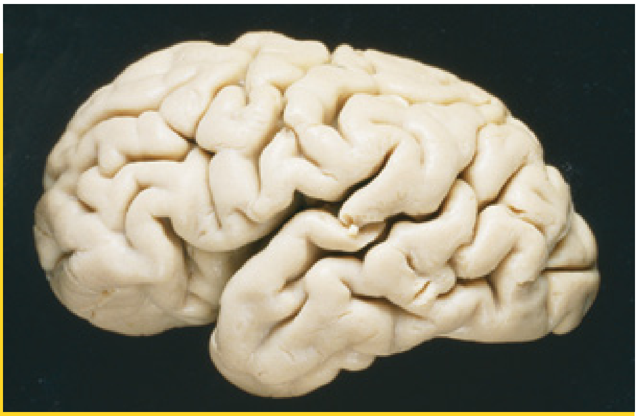
—Davide Castelvecchi

Best of the Blogs

EVOLUTION

Helpless by Design?

The timing of human birth may have more to do with a mother's caloric restrictions than with infant brain size



Human babies enter the world utterly dependent on caregivers to tend to their every need. Although newborns of other primate species rely on caregivers, too, human infants are especially helpless because their brains are comparatively underdeveloped. Indeed, by one estimation, a human fetus would have to undergo a gestation period of 18 to 21 months instead of the usual nine to be born at a neurological and cognitive development stage comparable to that of a chimpanzee newborn. Anthropologists have long thought that the size of the pelvis has limited human gestation length. New research may challenge that view.

The traditional explanation for our nine-month gestation period is that natural selection favored childbirth at an earlier stage of fetal development to accommodate selection for both large brain size and upright locomotion—defining characteristics of the human lineage. But when Holly M. Dunsworth of the University of Rhode Island and her colleagues tested this so-called obstetrical dilemma hypothesis, their findings did not match its predictions. The researchers argue that instead of fetal brain expansion being constrained by the dimensions of the pelvis, the dimensions of the human pelvis have evolved to accommodate babies, and some other factor has kept newborn size in check.

That other factor, they contend, is Mom's metabolic rate. Data from a wide range of mammals suggest that there is a limit to how large and energetically expensive a fetus can grow before it has to check out of the womb. Building on an idea previously put forth by study co-author Peter T. Ellison of Harvard University, known as the metabolic crossover hypothesis, the team proposes that by nine months or so the metabolic demands of a human fetus threaten to exceed the mother's ability to meet both the fetus's energy requirements and her own, so she delivers the baby. Dunsworth and her collaborators published their findings online in August in the *Proceedings of the National Academy of Sciences USA.*

When I asked paleoanthropologist Karen Rosenberg of the University of Delaware, an expert on the evolution of human birth, what she thought about the new work, she called it "important and interesting." Yet "just because there's a metabolic moment when it becomes reasonable to have a baby doesn't mean it isn't also true that the pelvis is a trade-off between giving birth and walking on two legs," she contends.

Rosenberg additionally noted—and I found this especially fascinating—that the authors mention the possibility that the timing of birth actually optimizes cognitive and motor neuronal development. That idea, described by Swiss zoologist Adolf Portmann in the 1960s, is worth pursuing, she says. "Maybe human newborns are adapted to soaking up all this cultural stuff, and maybe being born earlier lets you do this," Rosenberg muses. "Maybe being born earlier is better if you're a cultural animal." Food for thought. *—Kate Wong*

Adapted from the Observations blog at blogs.ScientificAmerican.com/observations

COMMERCE

Breaking the Ice

Russia pours money into a new nuclear-powered vessel

Russia's dream to dominate the Arctic will soon get a boost with a nuclear-powered icebreaker designed to navigate both shallow rivers and the freezing depths of the northern seas. In August, Rosatomflot, Russia's atomic fleet, inked a deal to begin construction of a massive new vessel that can blast through ice around three meters thick at a price of about $1.2 billion.

Powered by two RITM-200 compact pressurized water reactors generating 60 megawatts, the new model will have liquid ballasts, allowing it to alter its draft (the depth of the loaded vessel in the water) between 8.5 to 10.8 meters. The icebreaker will thus have access to both Siberian rivers that extend far into Russia and deep Arctic waters.

Why the effort and cost? "Climate change is a pivotal factor in accelerating Russia's interest in icebreakers," says Charles Ebinger of the Brookings Institution. "We are seeing a major change in the Northern Sea Route, which is a transport route along Russia's north coast from Europe to Asia. Just in the past few years, with less and less permanent sea ice, maritime traffic across the Russian Arctic has risen exponentially."

The expectation is that the melt will continue, but sections of the route still would require icebreakers to keep it open year-round. The icebreakers are also crucial for collecting data on Russia's continental shelf borders, which are needed to stake a claim to exclusive economic rights along vast tracts of the Arctic and to fend off other claimants, such as the U.S., Canada, Norway and Denmark. Russia argues that an undersea formation called the Lomonosov Ridge is an extension of Siberia's shelf and belongs to Russia exclusively.

Russia is the only country in the world currently building nuclear icebreakers and has a fleet of about half a dozen in operation, along with a larger fleet of less powerful, diesel-powered icebreakers. *—Eve Conant*

Conant traveled to Russia on a grant from the Pulitzer Center on Crisis Reporting. Adapted from the Guest Blog at blogs.ScientificAmerican.com/guest-blog

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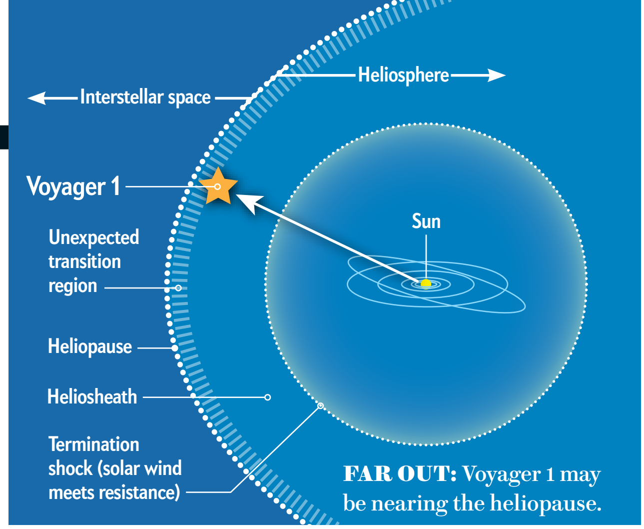
SPACE

The Last Frontier

Physicists try to puzzle out Voyager 1's position as it approaches interstellar space



FAR OUT: Voyager 1 may be nearing the heliopause.

JEN CHRISTIANSEN

It's been a long, strange trip out of the solar system for NASA's Voyager 1 spacecraft, and it may be a bit longer still.

Voyager 1, which launched 35 years ago, has ventured farther from Earth than any other spacecraft. The probe is now 18.2 billion kilometers from the sun—more than three times the average distance of Pluto. Voyager 1 is well on its way to an astonishing feat—escaping the sun's jurisdiction and venturing into interstellar space. Yet a new study suggests that the craft is further from taking that unprecedented step than had been assumed.

Nearly eight years ago the probe crossed into the heliosheath, where the solar wind (plasma from the sun) begins to slow because of push back from interstellar plasma. And in 2010 the velocity of the solar wind at Voyager 1's back unexpectedly dropped all the way to zero. Researchers expected that as Voyager 1 drew near to the boundary between the heliosheath and interstellar space, known as the heliopause, it would encounter solar plasma deflected sideways by interstellar plasma flows.

Yet in the September 6 issue of *Nature,* Robert B. Decker of the Johns Hopkins University Applied Physics Laboratory and his colleagues reported that no deflection is taking place. The new study raises two possibilities: either Voyager 1 has not yet approached the heliopause, or else plasma moves in unexpected ways there.

By one previous estimate, the heliopause could be just ahead of humankind's most well-traveled emissary, or it could lie as many as seven years' travel time ahead. The new findings favor the latter possibility. Decker, however, has newer data that further complicate predictions. In recent months Voyager 1 has registered a mixing of local and interstellar particles that could mark Voyager's arrival at another unexpected boundary—or a new domain of space. *—John Matson*

Maryn McKenna is a journalist, a blogger and author of two books about public health. She writes about infectious diseases, global health and food policy.

Virtues of the Virtual Autopsy

Medical imaging offers new ways to examine the deceased

Once a common medical procedure, the standard autopsy is passing out of use. In the 1970s bodies underwent postmortem examination in nearly 20 percent of deaths in the U.S. By 2007 the rate had fallen to 8.5 percent of all deaths and to only 4.3 percent of deaths caused by disease.

The reasons for the decline are well documented. Autopsies reveal medical mistakes, making doctors and hospitals uncomfortable. Medicare and private insurance do not reimburse providers for the procedures, so families must pay in full. And in the increasingly diverse U.S., members of some religions, such as Orthodox Judaism or Islam, object to dissecting a body after death.

Yet autopsy is a time-honored and reliable tool for confirming, or questioning, the actions of both medicine and law enforcement, so pathologists have looked for a viable alternative. Inspired by rapid technological improvements, researchers in several countries have been exploring the possibility that medical imaging—in particular, MRI and CT scans—might substitute a "virtual autopsy" for the more traditional variety.

"The findings so far are mixed," says Elizabeth Burton, a visiting associate professor of pathology at Johns Hopkins University. Virtual autopsy, she says, "is better for examining trauma, for wartime injuries, for structural defects. But when you start getting into tumors, infections and chronic conditions, it's not as good, and I doubt it will ever be better."

After about a decade of research, proponents concede that various difficulties—including high cost, competition for access to imaging machines and some inherent limitations of the technology—will likely prevent virtual autopsies from fully replacing the hands-on version. Nevertheless, the new techniques are answering cause-of-death questions that have frustrated traditional autopsies and are sidestepping religious objections. By enhancing medical education and suggesting improvements in emergency care, virtual postmortem examination is helping the living, too.

FORENSIC FRONTIER

POSTMORTEM IMAGING began as a laboratory technique in legal investigations. Dissection usually destroys tissues, but a research group in Bern, Switzerland, recognized that advances in imaging technology would let them look deep into tissues while preserving evidence. In the early 2000s they combined MRI and CT scanning with computer-aided 3-D reconstruction to prove causes of death for difficult cases, which included drownings, flaming car crashes, and severe injuries to the skull and face.

Their process, which they dubbed "virtopsy," ignited interest in applying postmortem imaging to other forms of traumatic injury. Since 2004 the U.S. military has performed x-rays and CT scans on the bodies of every service member killed where the armed forces have exclusive jurisdiction—that is, not just on battlefields abroad but on U.S. bases as well. Imaging "is an adjunct to the traditional external and internal postmortem exam," says Edward Mazuchowski, chief deputy medical examiner in the Armed Forces Medical Examiner System. "It allows us to identify any foreign bodies present, such as projectiles. X-rays give you the edge detail of radio-opaque or metallic objects, so you can sort out what the object might be, and CT, because it is three-dimensional, shows you where the object is in the body."

Along with analyzing causes of death, the virtual exams help to assess the accuracy of medical care in the field. Through imaging, examiners can detect whether medical devices, such as breathing tubes and long needles that can decompress a collapsed lung, performed as expected or fell short. Those analyses spur improvements such as lengthening needles to make sure they penetrate soldiers' sturdy musculature, as well as redesigning body armor to protect against the shrapnel scattered in unpredictable patterns by improvised explosive devices.

Virtual autopsy has moved into civilian forensics as well. In Melbourne, Australia, postmortem CT scanning has been part of legal investigations of deaths since 2005. In the U.S., at least two state medical examiners' offices, in New Mexico and Maryland, routinely use it. The Maryland office, according to Chief Medical

COURTESY OF ANDERS PERSSON *Center for Medical Image Science and Visualization*

Examiner David Fowler, applies CT to roughly half its autopsies, which amounts to about 2,000 cases a year. Imaging has proved invaluable, he says, for "pediatric cases, motor vehicle collisions and drownings" and has revealed causes of death in cases where dissection would destroy evidence, such as air sucked into blood vessels during trauma or dialysis and sports injuries to the vertebral artery, which snakes through the bones of the neck.

In hospitals, the value seems more mixed. Two 2009 research reviews by teams in the U.K. and the Netherlands found that virtual autopsies differed widely in accuracy, depending on whether the deceased was an infant, child or adult and on whether the cause of death was trauma or an infectious or chronic disease.

This past January a study conducted among intensive care unit patients in Germany compared diagnoses made before death with the results of both traditional and virtual autopsy in 47 patients and with only virtual autopsy in another 115 whose families refused standard autopsy. Virtual autopsies confirmed 88 percent of diagnoses made before death, not far behind the 93 percent rate for traditional postmortem exams. Although virtual autopsies tended to miss fatal heart attacks and blood clots in the lung and major blood vessels, traditional autopsies were not perfect either: they missed important fractures, fluid around the heart and collapsed lungs.

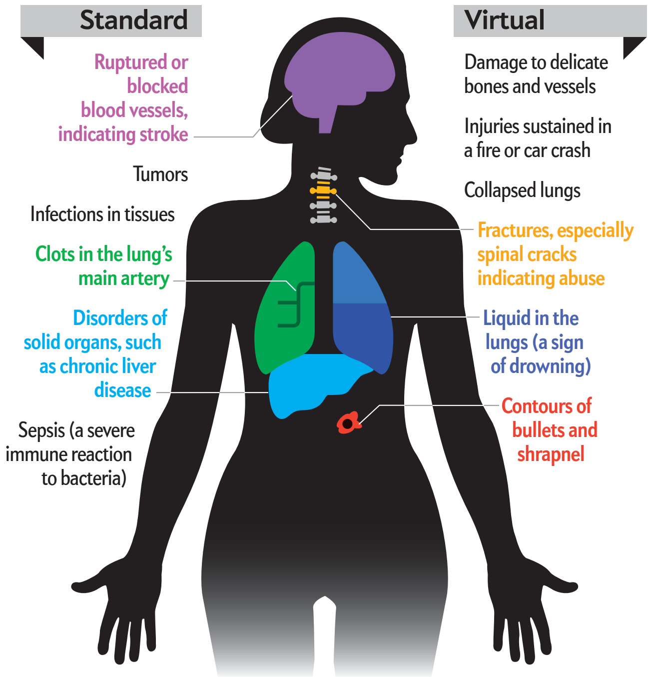
Dominic Wichmann, a specialist in internal medicine at University Medical Center Hamburg-Eppendorf in Germany and the study's first author, says the large number of instances where postmortem exams were refused underlines a situation in which virtual autopsy is essential: cases where cause of death is uncertain, but a standard autopsy violates religious rules.

Although no one keeps comparative records, the U.S. institution with the most virtual-autopsy experience may be Massachusetts General Hospital, which has conducted more than 125 procedures since 2010 under the direction of Mannudeep Kalra. He says that virtual autopsies help to establish frank causes of death such as air embolisms. Its biggest apparent shortcoming—failure to identify cardiovascular disease—is easily explained, he says: there is no circulation to move around the contrast medium that illuminates blood vessels from the inside. To solve this problem, several research teams are contemplating using heart-lung machines or similar pumps.

ON THE TABLE

MASS GENERAL, a teaching hospital of Harvard Medical School, is one of various academic medical centers to invest in the latest iteration of postmortem imaging technology: a virtual-autopsy table—essentially a giant iPad—that transforms the data from the scans into a 3-D animated image that doctors can "dissect" layer by layer with hand gestures. The Case Western Reserve University School of Medicine uses a virtual-autopsy table built by Swedish firm Sectra AB, while Harvard, Stanford University, the University of Texas at Austin and the University of Wisconsin–Madison have bought tables built by Silicon Valley–based Anatomage.

The biggest barrier to wider adoption of virtual autopsy is the cost of equipment and personnel. Virtual-autopsy tables are expensive; Anatomage's costs $60,000. The scanners used for MRI and CT cost hundreds of thousands of dollars, but most medical centers already have them. The true challenge is finding ways to



WHICH IS BETTER? Standard and virtual autopsies best identify different types of afflictions (*above*). Classic autopsies more effectively reveal disrupted blood flow, whereas virtual autopsies leave delicate tissues undisturbed and circumvent religious objections to opening up bodies after death.

pay technicians because autopsies—real or virtual—are not reimbursed procedures.

"I think compensation is going to be the rate-limiting step," says Gregory Davis, a pathology professor at the University of Kentucky College of Medicine. Hospital radiology departments, he points out, already have hectic schedules full of appointments with paying patients. Establishing a virtual-autopsy program often requires staff and faculty to work outside standard hours and obtain scarce grants or donate their time.

Given these issues of cost, radiologists will probably not replace pathologists as final arbiters of cause of death. Still, many pathologists think virtual autopsy is a crucial adjunct to traditional autopsy. And the resulting images, whether rendered on an Anatomage or presented on a laptop, could provide medical students with something they sorely need: an opportunity to participate in a vanishing practice. Anatomage markets its table as a teaching tool that allows students to practice surgery and lengthy dissection techniques, which heretofore required dead bodies.

"So few autopsies are being done now that many medical students get out of school never having seen one," Davis says. "And yet in medicine, autopsy is the most powerful quality-control technique that we have and the reason we know as much as we do about many diseases and injuries. Using imaging could bring back a familiarity with autopsy, and that is definitely worthwhile." SA

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Illustration by Thomas Porostocky

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

To Track My Thief

A guy stole my iPhone. I tracked it and posted his address online. Was that wrong?

When I boarded an Amtrak train this summer, I had no idea what kind of ride I was in for.

Upon arrival at my home stop in Connecticut, I realized that my iPhone was missing. I still had hope, though. Apple's free Find My iPhone service uses GPS, Wi-Fi and cellular information to locate lost i-gadgets on a map. After a couple of days, Find My iPhone e-mailed me to announce that it had found my phone—a map revealed it to be at a house in Seat Pleasant, Md.

Well, great. How was I going to retrieve a phone five states away? On a nutty whim, I posted a note to my Twitter followers about my lost phone. "Find My iPhone shows it in MD. Anyone want to help me track it down? ADVENTURE!" And I included a map showing the green locator dot over a satellite image of a nondescript house.

Within an hour the quest to recover my phone was on blogs, Twitter, and even national newspapers and television shows. "Where's Pogue's phone?" became a high-tech treasure hunt.

Using the address provided by Find My iPhone, local police got involved. The homeowner confessed to stealing the phone—no doubt baffled as to how the police had known exactly how to find him. And a day later I had the phone back. (I decided not to press charges.)

To me, that was that. Modern tech + good old-fashioned police work = happy ending, right?

Not for everyone. Lots of people were disturbed by the affair. They saw my posting the thief's address as a gross violation of his privacy.

"Are there to be ANY limits in this country?" wrote one reader. "Mr. Pogue … not only … crowdsourced instant 'deputies,' giving [them] detailed maps of the device's location but got the police to go to that location. That location is someone's home. What's the presumption of privacy there?"

My initial thought was: "Wait a minute—we're expressing sympathy for the *thief?*" When you steal something, don't you risk giving up some rights? How was my Twitter post any different from the "wanted" posters of suspects' photographs that still hang in post offices?

Of course, the difference in this case is that I, not law enforcement, posted the map and began the chase. Does that constitute a breach of the thief's rights? Is this a slippery slope into a world where the Internet's citizens become digital vigilantes?

Those are tricky questions. Even when the government or law-enforcement agencies want to get cell location information, the law is not always clear-cut. Sometimes the police require a warrant to obtain such information from cell phone companies; in other instances, they do not. In my case, there's not even much law to guide us, says Chris Soghoian, a privacy researcher at Indiana University Bloomington. A bill proposed last year in Congress, nicknamed the GPS Act, would have addressed "find my phone" services, saying that it's "not unlawful" for the owner of a stolen phone to use geolocation information to help an investigation.

It is possible, Soghoian says, that I violated some kind of state harassment or stalking statute. For the most part, however, both the legal and ethical ramifications of my crowdsourced phone quest are nothing but murk. It would have been better if I had been able to recover the phone without blasting a photograph of the guy's home to the Internet at large. It would have been better if he hadn't taken my phone at all or had responded to the "Reward if found" messages I sent to its screen. Yet combining the powers of geotracking and social networking seemed such an obvious tactic that, at the time, I hardly gave it a second thought.

In the end, maybe what society really needs is an app called Find My Moral Compass. SA

SCIENTIFIC AMERICAN ONLINE
Apps to find your lost phone: ScientificAmerican.com/nov2012/pogue

Illustration by Harry Campbell

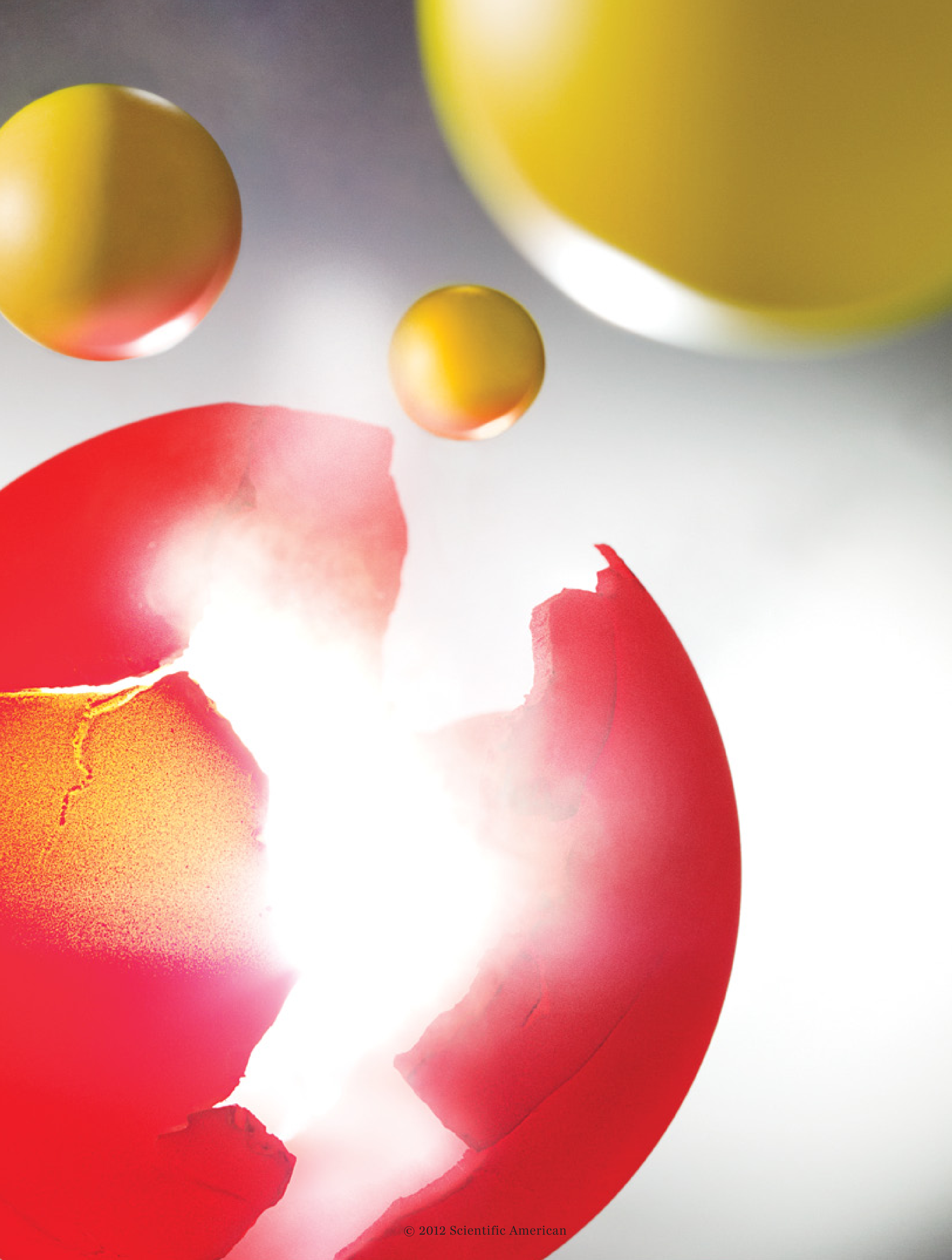
PARTICLE PHYSICS

THE INNER LIFE OF QUARKS

What if the smallest bits of matter actually harbor an undiscovered world of particles?

By Don Lincoln

Photograph by Craig Cutler



Don Lincoln, who has been interested in quark and lepton substructure for decades, is a senior physicist at Fermilab. He splits his research time between Fermilab and CERN and, in the occasional spare moment, also writes books and articles on particle physics for the public. He lives in the Chicago suburbs with his family and a particularly hirsute cat.

THE UNIVERSE IS A COMPLEX AND INTRICATE PLACE.

We can move easily through air and yet not through a wall. The sun transmutes one element to another, bathing our planet in warmth and light. Radio waves have carried a man's voice to Earth from the surface of the moon, whereas gamma rays can inflict fatal damage on our DNA. On the face of it, these disparate phenomena have nothing to do with one another, but physicists have uncovered a handful of principles that fuse into a theory of sublime simplicity to explain all this and much more. This theory is called the Standard Model of particle physics, and it encapsulates the electromagnetic forces that make a wall feel solid, the nuclear forces that govern the sun's power plant, and the diverse family of light waves that both make modern communications possible and threaten our well-being.

The Standard Model is one of the most strikingly successful theories ever devised. In essence, it postulates that two classes of indivisible matter particles exist: quarks and leptons. Quarks of various kinds compose protons and neutrons, and the most familiar lepton is the electron. The right mix of quarks and leptons can make up any atom and, by extension, any of the different types of matter in the universe. These constituents of matter are bound together by four forces—two familiar ones, gravity and electromagnetism, and the less familiar strong and weak nuclear forces. The exchange of one or more particles known as bosons mediates the latter three forces, but all attempts to treat gravity in the microrealm have failed.

The Standard Model leaves other questions unanswered as well, such as: Why do we have four forces and not some other number? And why are there two types of fundamental particles rather than just a single one that handles everything?

These are intriguing problems. Nevertheless, for a long time now a different puzzle has captured my attention and that of

IN BRIEF

In 1869 Dmitri Mendeleev created the periodic table of chemical elements by noticing that elements' properties fit into a repeating pattern, which physicists later explained as a consequence of atomic structure. A similar story may be playing out in particle physics again today.

The 12 known elementary particles have their own repeating patterns, suggesting they are not truly fundamental but actually tiny balls containing smaller particles, which physicists tentatively call preons.

Other evidence argues against this possibility. The Large Hadron Collider at CERN, along with several lesser-known experiments, may finally settle the question.

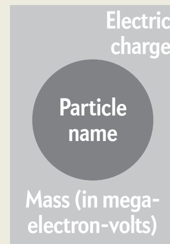
many other physicists. The Standard Model views quarks and leptons as indivisible. Astoundingly, though, various clues imply that they are instead built of still smaller components. If quarks and leptons are not fundamental at all, and smaller bits do in fact exist, their presence will force extensive revisions of our theories. Just as nuclear power was inconceivable before Ernest Rutherford discovered the structure of the atom in 1911, unveiling another layer of the subatomic onion will certainly reveal phenomena we cannot yet imagine.

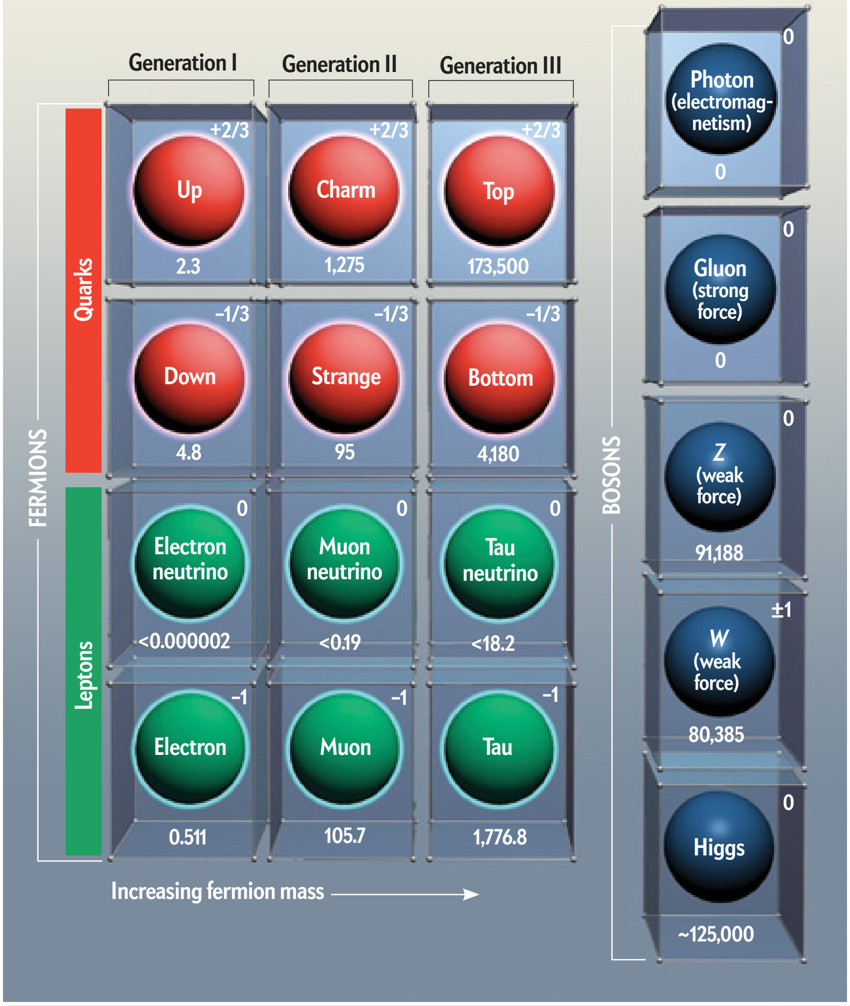
Resolving this issue requires scientists to smash particles together at extremely high energies. Since the observation of quarks in the 1970s, we have lacked the tools that might allow us to peer inside them. But now the Large Hadron Collider (LHC) at CERN near Geneva—the same machine that recently found evidence for the Higgs boson, the last undocumented particle in the Standard Model—is gaining speed and could be up to the task.

THE STANDARD MODEL

The Particle Landscape

All of particle physics rests on a theory known as the Standard Model, which lays out the fundamental particles that exist in nature, as well as the forces that govern them. The Standard Model includes two main families of particles: fermions, which include all the constituents of matter, and bosons, which include all the known force-carrying particles. Fermions come in three generations of progressively greater mass.





GENERATION GAPS

THE FIRST HINTS of structure in quarks and leptons emerged from research into another—still unsolved—poser, related to the numbers of different kinds of quarks and leptons that have been discovered. Protons and neutrons consist of two types of quarks, called the up quark and the down quark. Up quarks have +2/3 the electrical charge of the proton, and down quarks have −1/3 of the proton's charge. Although only these two types of quarks, plus electrons, suffice to make up the matter of the universe, other quarks have been observed. The strange quark has the same charge as the down quark, but it is heavier. The bottom quark is an even heavier version. Similarly, the charm quark is a heavier cousin of the up quark, with the superheavy top quark rounding out the up quark family. Particle physicists have observed all these quarks, but the four heavier ones decay, in fractions of a second, into the lightest two.

The electron also has heavy, unstable cousins, the muon and the even heavier tau lepton, both of which have the same charge as the electron. And the known menagerie of particles includes three copies of neutrinos, all of which are superlightweight and electrically neutral.

This cornucopia naturally led physicists to ask: Given that the up quark, down quark and electron are the only particles necessary to build a universe, why do they have so many cousins? The question can be encapsulated in Nobel Prize–winning physicist I. I. Rabi's oft-quoted quip when he learned of the discovery of the muon: "Who ordered that?"

One way scientists went about tackling the mystery of populous particle families was to construct a chart delineating the features of all known elementary particles [*see box above*], analogous to the periodic table of chemical elements. The periodic table offered physicists the first hints that the chemical elements might not be fundamental, that systematic patterns in the atom's inner structure might account for similar properties of elements in particular rows and columns.

The table of quarks and leptons has three columns called generations (which is why the mystery of particle multiplicity

Illustrations by Malcolm Godwin

is now referred to as the generation problem). Generation I, at the far left, includes the up and down quark as well as the electron and electron neutrino—everything needed to explain our familiar universe. Generation II contains the somewhat more massive versions of the same particles; generation III has the most massive of all.

The Standard Model treats the quarks and leptons as point-like particles without any internal structure. But the patterns within the table, as within chemistry's periodic table, raise the possibility that the differences in generations stem from the configuration of even smaller building blocks of matter within quarks and leptons.

Another historical precedent, near the dawn of the 20th century, that may have relevance in the search for the quark's underlying structure is the discovery of radioactive decay. Through a process not understood at the time, one element can transmute into another. We now know that by changing the number of protons and neutrons in the nucleus, it is possible to achieve the goal of medieval alchemists and convert lead into gold. The range of possible transmutations is even wider, as nuclear alchemy can even convert a neutron into a proton (or the reverse) by changing the identity of their constituent quarks. This transformation occurs via the weak nuclear force, which can also transmute leptons, although quarks cannot be changed into leptons, or vice versa. Just as the conversion of one element into another reflects the complex inner workings of the atom, so the metamorphosis of the quarks and leptons may provide yet another hint of even finer details within those particles.

PREONS FOR BEGINNERS

A Particle Cookbook

Physicists have proposed various concepts for preons—the particles that might make up quarks and other elementary particles. One notable model (*below*) was proposed in 1979 by Haim Harari, then at the Stanford Linear Accelerator Center, and Michael A. Shupe, then at the University of Illinois at Urbana-Champaign. Their scheme posits two kinds of preons and an antimatter version of each, which could comprise both the particles of matter, or fermions (*top*), and the particles of force, or bosons (*bottom*).

Particles of Matter (Fermions)

The two preons in this model can be represented as + and 0. The + has a charge of +1/3, and the 0 has a charge of zero. Each has a corresponding antimatter companion with the opposite charge: – (–1/3) and $\bar{0}$ (zero). In Harari and Shupe's model, the quarks and leptons are each composed of three preons.

CHARGE	PREON CONTENT	PARTICLE
+1	+ + +	Antimatter electron
+2/3	+ + 0	Up quark
+1/3	+ 0 0	Antimatter down quark
0	0 0 0	Electron neutrino
0	$\bar{0}\,\bar{0}\,\bar{0}$	Electron antineutrino
–1/3	– $\bar{0}\,\bar{0}$	Down quark
–2/3	– – $\bar{0}$	Antimatter up quark
–1	– – –	Electron

Particles of Force (Bosons)

In groupings of twos and sixes, the same preons can also describe the bosons, whose transfer mediates the subatomic forces: electromagnetism (photon), the strong nuclear force (gluon) and the weak nuclear force (W^+, W^-, Z bosons). The details for gluons, the subatomic particles that bind quarks together inside atomic nuclei, are a bit more complicated and are omitted here.

CHARGE	PREON CONTENT	PARTICLE
+1	+ + + 0 0 0	Positive *W* boson
–1	– – – $\bar{0}\,\bar{0}\,\bar{0}$	Negative *W* boson
0	0 0 0 $\bar{0}\,\bar{0}\,\bar{0}$ + + + – – – + + – – 0 $\bar{0}$ + – 0 0 $\bar{0}\,\bar{0}$	*Z* boson (four versions)
0	+ –	Photon

PART AND PARTICLE

MANY HYPOTHETICAL building blocks for quarks and leptons have emerged, each with a different name, but the term "preon" has stuck as a generic descriptor for all of them. In most cases, the same name applies to the constituents of the particles that carry the forces acting on these bits of matter.

As an illustration, consider a straightforward model proposed independently in 1979 by Haim Harari, then at the Stanford Linear Accelerator Center, and Michael A. Shupe, then at the University of Illinois at Urbana-Champaign, and subsequently extended in 1981 by Harari and his student Nathan Seiberg, both then at the Weizmann Institute of Science in Rehovot, Israel [*see box at left*]. They proposed that two kinds of preons exist, one with an electric charge of +1/3 and one with a charge of zero; in addition, each of these preons has an antimatter companion with opposite charge: –1/3 and zero, respectively. These preons are fermions—particles of matter—and each quark and lepton contains a unique mix of three preons. Two preons of +1/3 charge and one with zero charge, for instance, make an up quark, whereas the up quark's antimatter counterpart contains two preons of –1/3 charge and one with zero. The force-carrying bosons, meanwhile, consist of unique six-preon combinations. The positively charged *W* boson, for instance, which carries the weak nuclear force that acts on both quarks and leptons, has three +1/3 preons and three zeroes.

Using a series of sensible assumptions, Harari and Shupe postulated the preon content of all the particles of the first generation. The same building blocks can also account for gluons, the subatomic particles that mediate the strong nuclear force to bind quarks together inside protons and neutrons, as well as the other force-carrying bosons.

The trick in formulating any underlying structure of the well-known quarks, leptons and bosons is accounting for the myriad interactions of those particles and forces. Indeed, preons can provide a sensible language for describing subatomic processes. For instance, consider an up quark colliding with an antimatter down quark, yielding a positively charged *W* boson that decays into an antimatter electron, or positron, and an electron neutrino. In the preon model devised by Harari and Shupe, the incoming quarks, with their three preons apiece, combine in the collision to generate a *W* boson, now containing all three +1/3 charges and all three zero charges. Then the *W* boson comes apart, spitting out a different configuration of the same six preons: one positron (with the three +1/3 charges), and one electron neutrino (with the three zero charges).

Thus far I have discussed what might be called quark and lepton numerology. This is just a counting game, like balancing chemical or math equations, albeit a serious and feasible one. To be successful, a preon model must explain the quarks and leptons with a small number of building blocks and a few governing rules. After all, the hope is to find an underlying order that unifies superficially different particles, not a system of ad hoc definitions that accounts for their properties on a case-by-case basis. Such an explanation has been accomplished with preons, both in the Harari-Shupe model and in its successful competitors.

You may have noticed, however, that the discussion so far has included only the first generation of quarks and leptons. Things get murkier when we turn our attention to the second and third generations. Within the model proposed by Harari and Shupe, the higher generations are hypothesized to be excited states of the first-generation configurations. Just as electrons jump from one energy level to another in atoms, some unknown mechanism is thought to bind the preons together in a way that allows for multiple-particle generations from the same ingredients.

If this explanation seems a bit like hand waving, it is. Many of the details have not been worked out. The theoretical studies that first proposed the idea of quarks had a similar level of sophistication. It was only later that the strong force, which binds quarks together into protons and neutrons, was described mathematically. Still, the generation problem remains conspicuously unexplained, so several physicists have proposed competing models, including one in which one of the preons carries the generation number as well as a new charge called hypercolor, which binds the preons inside the quarks and leptons.

Although I have described a single theory of preons, do not be misled into thinking it is the only one out there. My theoretical colleagues are very smart and very creative. Literally hundreds of papers have been written proposing other preon models, although these models are often variations on a small number of basic themes. Some have preons with 1/6 charge, rather than the 1/3 in Harari and Shupe's model. Others have five preons in the quarks and leptons as opposed to three. Still others propose a mix of fermion preons and boson preons or different preon contents for the bosons than those laid out in the bottom table on the opposite page. The possibilities are actually quite rich. We physicists need more data to help weed out the alternatives.

Just as nuclear power was inconceivable before the discovery of atomic structure, unveiling a new layer of matter would reveal phenomena we cannot imagine.

Beyond inherent fascination with the notion that the smallest known pieces of matter might have smaller pieces still, many of us are interested in preons for another reason. If they exist, they could have something profound to say about another outstanding mystery in particle physics. The Standard Model postulates that the Higgs field is the source of mass for fundamental particles. Massive particles feel a sort of drag as they move through this ubiquitous field, whereas massless particles such as the photon glide through unmolested. If the preons that make up the second and third generations are the same as the first, presumably something about the preons enables the higher-generation particles to interact more with the Higgs field than the first generation does, thus giving the higher generations their greater mass. Whereas the Higgs mechanism can account for the masses of the particles, it cannot predict them.

Until a deeper theory is invented, the mass of subatomic particles can be determined only by measuring them one by one. Presumably by understanding the structure of quarks and leptons and how the generations differ, we will learn much more about the Higgs mechanism.

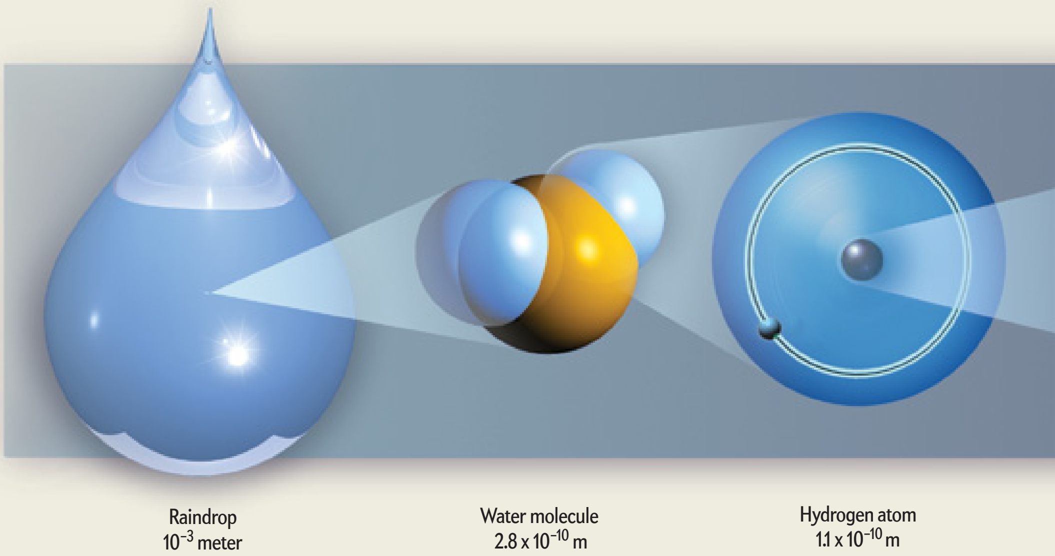
POTHOLES AND DETOURS

I SHOULD NOTE THAT preon theory is not without its problems. For starters, all experimental efforts to see preons have failed. That failure is disappointing but could stem simply from having inadequate equipment. Experimental questions aside, some concerns are intrinsic to the theory itself. It is a natural feature of "confining theories," so called in this context because the preons are confined inside the quarks and leptons, that the relevant masses are inversely proportional to the confinement size. Because quarks and leptons are much smaller than protons, this rule implies that a quark made of confined preons would be much more massive than a proton, which is itself made of quarks. The proton whole would be less than the sum of its parts—less, indeed, than the individual parts themselves.

Although this problem may seem insurmountable, physicists have managed to get around a similar kink related to bosons. A quark and antiquark, for instance, can make up a boson called a pi meson, in which the confinement conundrum also seems to pose a problem. Using an idea sketched out in 1961 by Jeffrey Goldstone, then at CERN, however, theorists have long realized that symmetries in the underlying theory could overcome this difficulty. Thus, the lightness of the pi meson was not really a surprise. Unfortunately, this approach applies only to bosons, not to fermions such as quarks. Yet in 1979 Gerard 't Hooft of the University of Utrecht in the Netherlands worked out a related approach that does work for fermions. Whether 't Hooft's concept is borne out in actual particles remains unclear, but his

Zooming In

If preons exist, they are almost unimaginably tiny. They would have to fit inside the quark, currently the smallest known particle of matter, which itself must be small enough to fit into the proton. In fact, all experiments to date are consistent with the quark having a size of zero, which would preclude any inner structure. But future experiments will zoom in for a closer look. A nonzero size for the quark would give the preon hypothesis a major boost.



ideas have at least shown that the theoretical roadblock of quark masses is not as formidable as it first appeared.

Preons are not the only avenue physicists have explored in hopes of solving the generation problem. One prominent alternative is the idea of superstrings, in which the ultimate building blocks of matter are not subatomic particles but tiny vibrating strings. Metaphorically, each of the Standard Model particles can be thought of as strings playing a different note and all of reality as an orchestra of superstrings playing a grand cosmic symphony. Happily, preons and superstrings can amiably coexist because the size scale of superstrings is much smaller than that of quarks and leptons. If superstrings exist, they could well make up not quarks and leptons but rather preons or even pre-preons or pre-pre-preons, depending on how many undiscovered onion layers of matter exist.

Another alternative to the idea of preons as ordinary, albeit undiscovered particles emerged in 2005, when Sundance Bilson-Thompson of the University of Adelaide in South Australia devised a way of describing preons as twisted braids of spacetime. This model is still in its infancy, but physicists are exploring its implications, not least because it offers one possible path to integrating a long-sought quantum theory of gravity into the Standard Model.

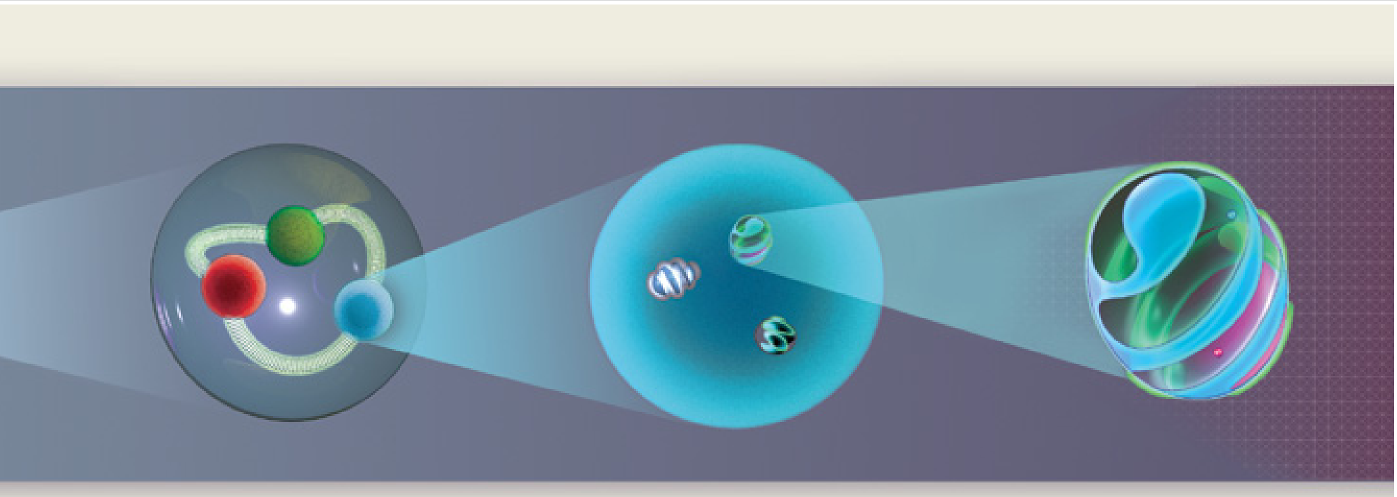
PROOF IN THE PREON PUDDING

PHYSICS IS ULTIMATELY an experimental science. No matter how clever the theory, if it fails to agree with measurement, it is wrong. So what can experimentalists do to prove or disprove the existence of preons? The Standard Model successfully describes the quarks, leptons and bosons of the universe without invoking preons, so physicists must look for subtle deviations from the Standard Model's predictions—tiny cracks in the edifice of modern physics. Two facets of the model in particular look like attractive areas to explore more closely.

The first is size. The Standard Model treats the quarks and leptons as pointlike—that is, particles with zero size and no inner structure. Finding a nonzero size for those particles would provide powerful evidence for preons. Measurements have shown that protons and neutrons have a radius of about 10^{-15} meter. Experiments at the world's leading particle colliders, past and present, have searched for evidence that quarks or leptons also have a measurable size. Thus far all the data are perfectly consistent with zero size or with a nonzero size as small as about 0.0002 to 0.001 times the size of a proton. To distinguish between those two possibilities (zero size versus very, very tiny), we need to make more precise measurements. The LHC is a discovery machine, and the huge amount of data expected from its current collisions and a scheduled upgrade in the accelerator's energy are two ways in which we can expect to learn more about the size of quarks and leptons.

Another way to demonstrate the existence of particle substructure—for leptons, at least—is to investigate the tightly related concepts of spin and magnetic moment. With some poetic license, an electron can be thought of as a spinning ball, and physicists quantify that property with a spin quantum number. Like all fermions, the electron is said to have spin 1/2. Because the electron is electrically charged, the combination of spin and charge confers a magnetic moment, which is just a fancy way of saying it turns the electron into a familiar magnet, with a north and south pole. Assuming a lepton is a pointlike particle with spin 1/2, it should have a single and specific magnetic moment. So if a measurement of the electron or muon turns up a magnetic moment that differs from the prediction, that result would strongly suggest that those particles are not pointlike and therefore could be composed of preons.

Physicists have long known that the magnetic moments of both the electron and muon do diverge somewhat from that of a pointlike particle. This small difference has nothing to do with preons, though, and can actually be explained within the Standard Model. Each lepton is surrounded by an evanescent cloud of so-called virtual particles, which flicker in and out of existence. Because this cloud has a size, it alters the magnetic



Proton
1.7 x 10^{-15} m

Quark
Less than about 10^{-18} m

Preon (theoretical)
Pointlike, or composed of smaller constituents

moment of the lepton ever so slightly—by about one part in 1,000. The effects of preons would be even smaller, but they could be detectable. New measurements on the horizon, at Fermilab's muon g-2 experiment, will be more than a factor of four more precise than those thus far achieved.

Physicists have also dug through collider data to look for particle decays that would be expected if preons exist and if the higher generations of particles are simply excited states of the first. One such process is a muon decaying into an electron and a photon. This decay has not yet been observed and, if it happens at all, occurs less than about one time in 100 billion.

Every direct measurement made thus far is consistent with the hypothesis that quarks and leptons are, indeed, pointlike, with spin 1/2. For those of us who think that the observed generations of subatomic particles are a tantalizing hint of undiscovered physics, the past few decades have been frustrating. But now we have real opportunities to explore new territory.

In 2011 the LHC collided beams of protons at an energy of seven trillion electron volts (7 TeV), 3.5 times the previous world record (held by Fermilab's Tevatron for more than a quarter of a century). In that one year the LHC delivered half as much data from collisions as the Tevatron did over its entire 28-year operating career. In 2012 CERN raised the LHC's energy to 8 TeV, with an expectation of quadrupling the collection of data before initiating a temporary shutdown of a year and a half to make repairs and improvements. The LHC should then resume operations in late 2014 or early 2015, colliding proton beams at 13 or 14 TeV and at a much faster pace.

The modest 2012 increase in energy might seem like a minor adjustment, but it will mean a lot for preon searches. The small change in beam energy will quintuple the number of collisions recorded at the highest energies, which probe the smallest sizes and which are exactly the kinds of events we need to inspect for evidence of preons. The upgrades of 2014 and 2015 will provide a breathtaking increase in capabilities.

In addition to the LHC, the Fermilab research program is undergoing a fundamental retooling, which will include a new ability to search for direct evidence of preons. Since the Tevatron was decommissioned in 2011, Fermilab's accelerators no longer tread the energy frontier of particle physics. Instead Fermilab is pushing forward into the intensity frontier, exploring rare phenomena with unprecedented precision. Two of the experiments most relevant to the search for preons will measure the magnetic moment of the muon and look for muons as they decay into an electron and a photon.

The future of hunting for structure within the quarks and leptons is brighter than it has been for a long time. As you read this article, my colleagues and I are combing through the huge amount of LHC data already taken. We are searching for evidence that quarks and leptons have a nonzero size. We are looking for a fourth generation of quarks and leptons and for some evidence that the force-carrying particles also have generations—that the *W* and *Z* bosons, which mediate the weak nuclear force, have heavier cousins.

The next few years will mark the start of a new foray into the subatomic realm, a journey the likes of which scientists last encountered more than 25 years ago, when the Tevatron began operations. Like intrepid adventurers of yesteryear, physicists are forging ahead and blazing a trail into the quantum frontier. SA

MORE TO EXPLORE

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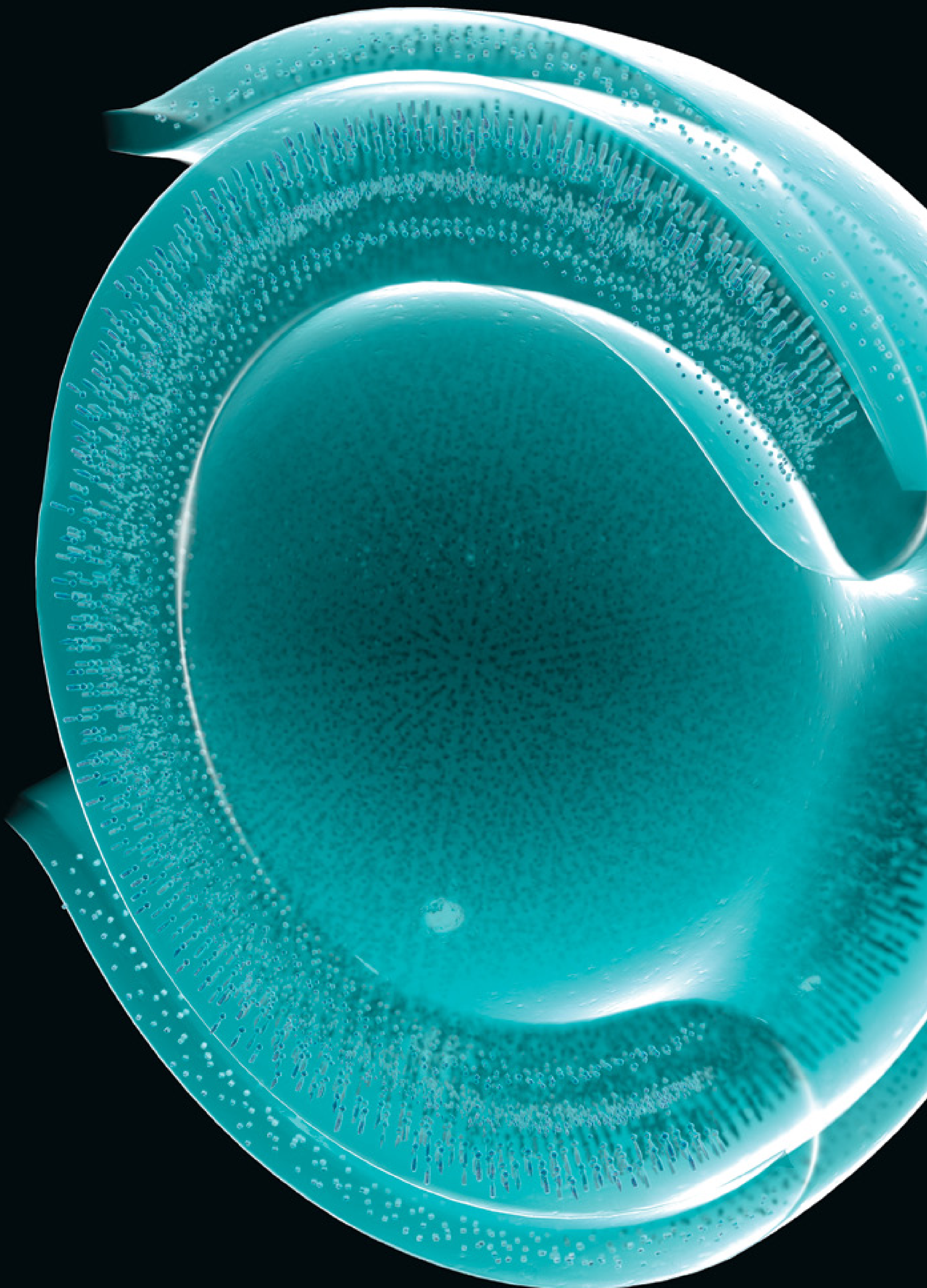
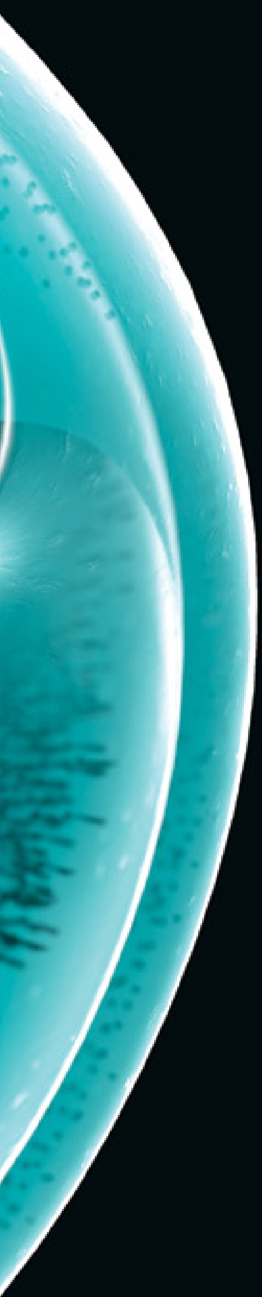
Explore an interactive version of the Standard Model of particle physics at **ScientificAmerican.com/nov2012/preons**





Grow Your Own Eye

Biologists have coaxed cells to form a retina, a step toward growing replacement organs outside the body

By Yoshiki Sasai

Illustrations by Bryan Christie

IN BRIEF

Stem cells give rise to all the organs in the body, a process that continues to fascinate and mystify the scientific world.

A leading Japanese group demonstrated the growth of both a human and mouse retina in a laboratory dish.

The event enables better understanding of brain development and may lead to eventual treatments for eye diseases.

Yoshiki Sasai is group director of organogenesis and neurogenesis at RIKEN Center for Developmental Biology in Kobe, Japan. He received his medical degree and a doctorate in molecular neurobiology from the Kyoto University Graduate School of Medicine.

IN THE WOMB, A BALL OF IDENTICAL CELLS GIVES RISE TO VARIED CELL TYPES THAT ULTIMATELY form highly ordered structures and then the full panoply of organs in the human body. The process advances according to an internal biological script that directs each fold and crease of tissue to assume exactly the proper shape and dimension.

Scientists familiar with this progression from simple parts to a complex system have never stopped contemplating embryonic development with a sense of muted wonder and a concomitant desire to replicate early development on top of a laboratory bench—both to understand the biology better and to translate the information into ways of repairing and replacing damaged tissues. Their time may have come. Recent successes in deciphering the intricacies of development have raised the prospect of replacement organs grown outside the body arriving in surgical suites within as little as 10 years.

My own optimism about that prediction comes from recent studies in my lab on stem cells, which go on to diversify into other cell types. We showed that, even when grown in culture, stem cells can give rise to a retina, a key structure within the eye that translates light from the outside world into electrical and chemical signals that are then relayed to the rest of the brain. In other work, my colleagues and I have also grown cortical tissue and a part of the pituitary gland. In doing these experiments, we have taken advantage of our expanding understanding of the body's own innate signaling systems to coax a flat layer of disconnected cells in a petri dish to form a contoured, three-dimensional structure. Making use of chemical signals we provided, the stem cells took it on themselves, in essence, to build their own retina. This success spurs hope that retinal tissue produced by such methods can help treat several eye disorders, including macular degeneration.

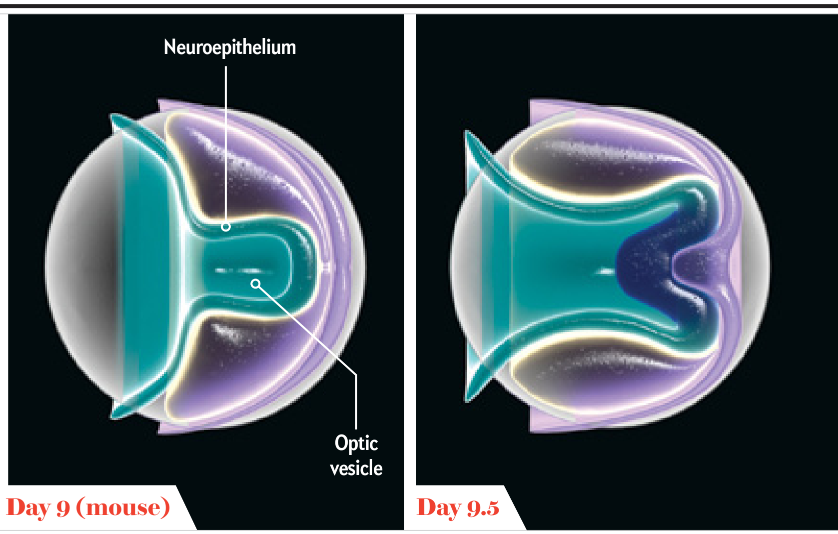
FLOATERS

WHEN MY LAB BEGAN its attempts to grow a retina, we were trying to answer basic questions about how it forms. We knew that the retina emerges from a part of the embryonic brain called the diencephalon. During early embryonic development a segment of the diencephalon expands to form the optic vesicle, a balloonlike structure. The vesicle then folds inward to assume

BASICS

Forming the Apple of an Eye

The development of the eye from a small wad of embryonic tissue begins when an interior layer, the neuroepithelium, folds outward, becoming the optic vesicle (*day 9*). The bud's outer layer then begins to indent as well (*day 9.5*), which results in development of the lens vesicle (*day 10*). Part of the optic vesicle folds to form the optic cup, which in concert with the lens vesicle becomes the retina and optic nerve and, at the exterior, the lens (*day 10.5*). The retina contains three distinct cell layers (*inset*): rods and cones; horizontal, bipolar and amacrine cells; and ganglion cells.



the shape of the optic cup, tissue that eventually morphs further to become the retina.

For more than a century biologists had debated the exact mechanism underlying the formation of the optic cup, a dispute that still lingers among scientists who study the developing brain. One looming question involves the role of neighboring structures, such as the lens and cornea. Some observers claim that the lens physically pushes the retina to bend inward, whereas others posit that the optic cup can form without the help of nearby lens tissues.

Seeing what is going on in live, developing animals is very difficult, and so about 10 years ago my group decided to see if we could learn more by isolating eye development—essentially by putting embryonic stem cells into a culture dish, exposing them to chemicals known to be involved in eye formation and watching what happened. Embryonic stem cells are the most immature type of stem cell and eventually go on to differentiate into all the body's diverse tissue types, from neurons to muscle cells.

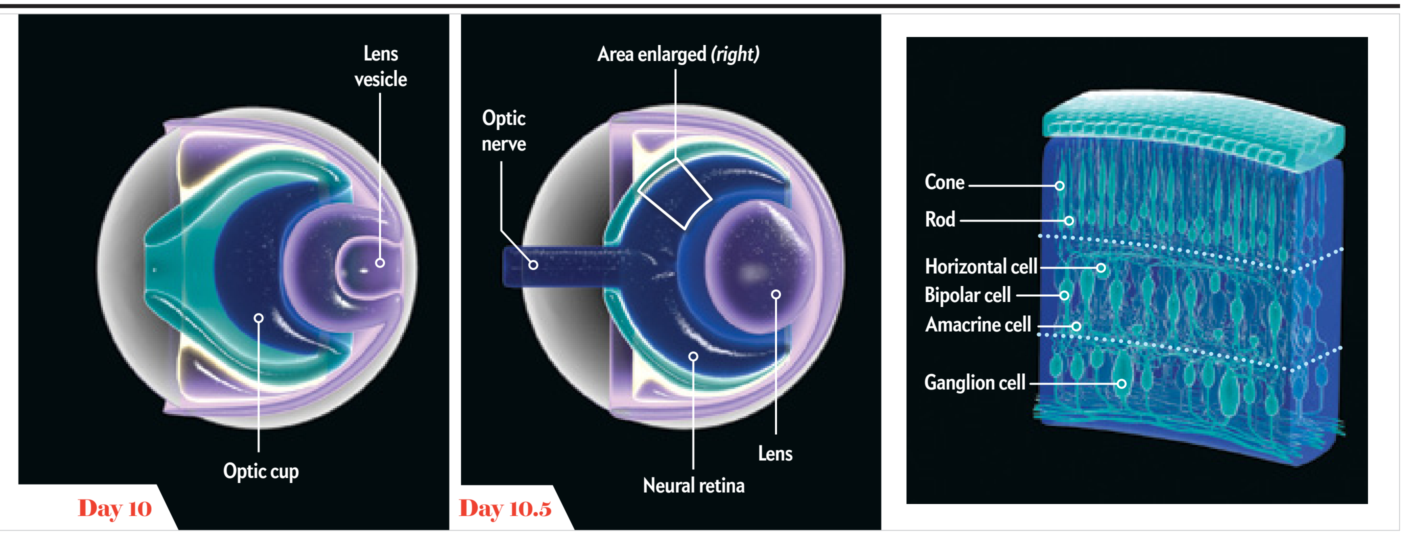
No techniques existed for generating organs from stem cells in culture. Attempts to use these cells to build a new organ had seeded individual cells on an artificial scaffold shaped like a bladder or an esophagus. Tissue engineers had mixed success in growing actual organs with this technique. For that reason, we tried a different approach. As a prelude to this process, we devised a cell culture method in 2000 for turning mouse embryonic stem cells into various types of neurons. We then put a single layer of embryonic mouse stem cells on a culture dish, along with "feeder" cells that transmit chemical signals that prompt the stem cells to mature beyond their embryonic state. We understood that this flat sheet does not replicate the three-dimensional contours of actual human organs, but we wanted to see if the cells' own chemical signaling might be enough to prod them to generate special types of neurons characteristic of the eye's early development process.

We did not have much success at first, but in 2005 we achieved a technical breakthrough by inventing a way to move beyond the two-dimensional constraints of our lab's earlier stem cell technology and allow the stem cells to float in a culture solution. We started to use this three-dimensional culture, termed a floating culture, for a number of reasons. First, a three-dimensional aggregation of cells can better generate complex tissue topology than one formed in a flat sheet. Second, one cell needs to communicate with another to develop into a complex structure, and a three-dimensional culture is more suitable for promoting such communications because cells can more flexibly interact with one another.

Applying this new method, we suspended separate cells in a tiny amount of a liquid medium in wells in a lab dish and found that they began to bind together with their well mates. These small cell aggregates, typically 3,000 cells per well, could then be coaxed to differentiate into the same kind of neural progenitors (immature neural cells) that populate the front of the brain. The cells then started to signal to one another and, after three to four days, spontaneously organized into a hollow sphere formed by a single-layer cell sheet, a neuroepithelium. We called this method of making the sheets a SFEBq (*s*erum-*f*ree floating culture of *e*mbryoid *b*ody–like aggregate with *q*uick reaggregation) culture.

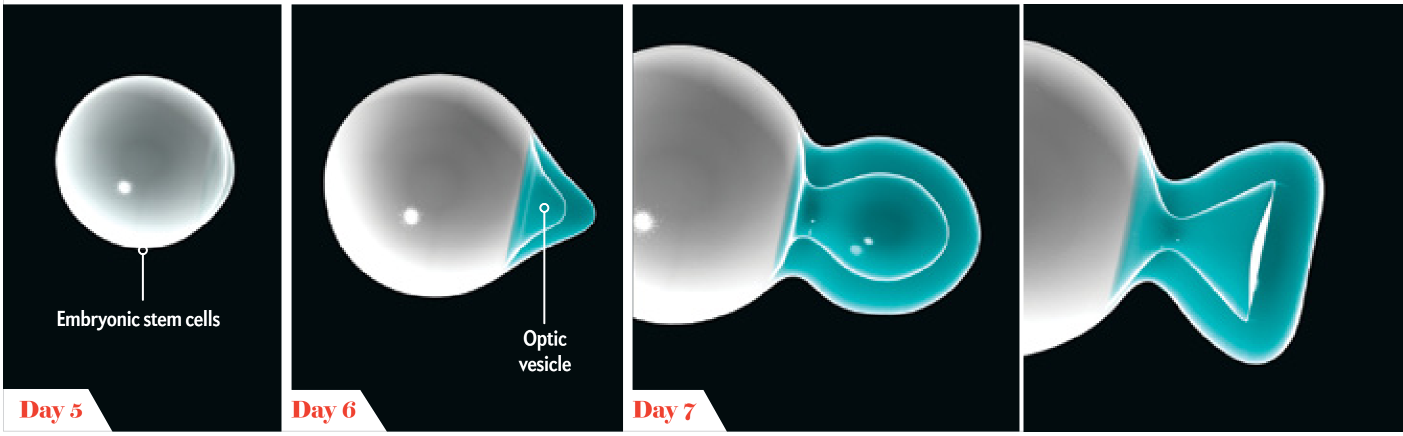
In the embryo, neuroepithelial cells eventually form specific brain structures after they receive external chemical signals from outside the cells. One of these signals triggers development of the diencephalon, which later gives rise to the retina and the hypothalamus (the brain region that controls appetite and a number of other basic bodily functions). Once we had gotten cells to form spheres in the lab, we attempted to induce the constituent cells to differentiate into retinal progenitors—precursors of mature retinal cells—by adding a cocktail of proteins (containing the chemicals that perform the same task in the embryo) to the SFEBq culture.

After these spheres remained in a floating culture for several more days, the retinal epithelial tissue spontaneously protruded outward, or evaginated, and formed optic vesicle–like structures. Moreover, the vesicles spontaneously changed shape: the epithelial part on the outside of the main body of the sphere folded inward. This movement generated a brandy glass–like shape resembling the optic cup of the embryonic eye. As seen in live animals, the optic cup derived from embryonic stem



Development in a Dish

Growing a retina in culture from embryonic stem cells recapitulates development of the eye that occurs in the womb. The technique is invaluable for basic researchers and may also lead to new treatments for people whose vision deteriorates. As the illustrations below show, embryonic stem cells aggregate and begin to form the very early optic vesicle after about five days of being



cells consisted of two walls: the outer epithelial wall and the inner wall of the actual retina.

In other words, aggregation of dissociated stem cells in a culture dish alone resulted in an ordered structure—a literally eye-popping result. Unlike in the embryo, no lens or cornea formed next to the optic cup. This finding gave a clear answer to the long-standing question of whether or not this protoretina requires external forces from neighboring tissues such as lens cells. Retinal formation, at least in vitro, is a self-organizing phenomenon based on an internal program that resides within these cells.

LAYERING A RETINA

NORMAL DEVELOPMENT as seen in embryos continued to proceed in the lab dish. When we subjected the optic cup to an additional two weeks in a floating culture, the tissue grew to approximately two millimeters in diameter, with the single-layered retina epithelium becoming, as in the embryo, a stratified structure containing all six categories of cells found in the postnatal retina. The laminated material contained an outer photoreceptor layer and an innermost layer of ganglion cells, which, in the body, connect the retina to the brain. In between, as would be expected in a true retina, were several connecting layers of cells called interneurons. As before, the formation of multiple layers occurred through an internal program that guides what kinds of cells to make and how to arrange them in a three-dimensional space.

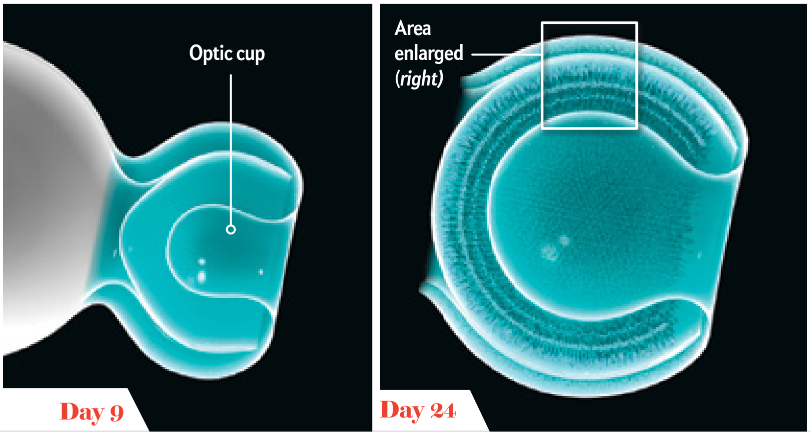
Our work is not over. Questions still persist as to how the optic cup forms and how a ball of cells generates a patterned structure. Spontaneous emergence of intricate shapes from a homogeneous clump of matter is known as symmetry breaking and occurs throughout embryonic development. If it were not for symmetry breaking, repeated cell divisions of the fertilized egg would not progress beyond an undifferentiated mass of cells. Our self-organizing embryonic stem cell culture appears to serve as an ideal experimental platform for understanding the elusive mechanisms of this process during mammalian embryogenesis.

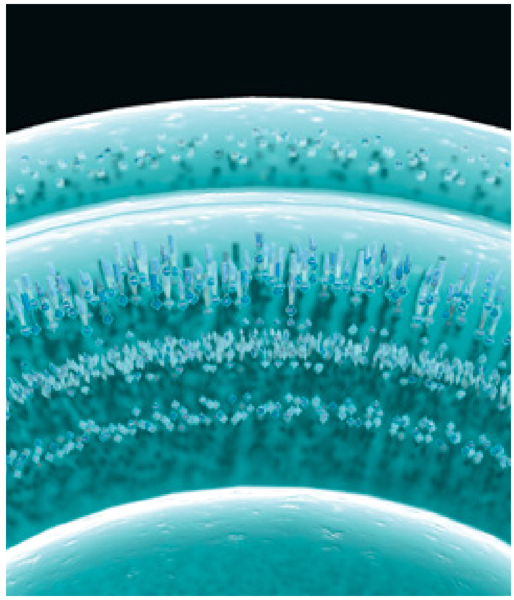
Another looming question relates to how the retinal epithelium, initially just a sheet of cells, programs the shaping of the optic cup. In general, mechanical force and stiffness control changes in epithelial tissue. By measuring the direction of force and tissue stiffness in different parts of the epithelium during formation of the optic cup in vitro, we found three steps that lead to formation of tissue structure. As the optic cup forms, stiffness in the retina diminishes, increasing flexibility. At the same time, cells at the junction of the retina and the epithelium assume a wedge shape, and finally the retina begins to fold inward because of its rapid expansion. These three steps are critical for optic cup formation. In fact, when these conditions related to tissue mechanics were introduced in a computer simulation, the familiar brandy glass shape emerged.

TO SEE CLEARLY

OF COURSE, PEOPLE WHO HEAR of our research want to know whether work on mouse embryonic stem cells will eventually help humans with eye ailments. We have made some progress in that direction. Notably my lab very recently reported successful formation of an optic cup and multilayered neural tissue derived from human embryonic stem cells. It is also expected that the same culture method should be applicable to human induced pluripotent stem cells—mature cells that were prodded to go through a reverse development process that allows them to behave like embryonic stem cells. We have also invented an improved cryopreservation method that can reliably store human embryonic cell–derived retinal tissue in liquid nitrogen.

All of this work will propel us toward medical applications of retinal tissue. For instance, we may be able to create artificial retinas that help researchers explore the pathology of common mixed with molecules called growth factors. The vesicle balloons out by day 7, and a few days later the structure collapses to form the optic cup, which by day 24 has delineated all the layers of the retina.





eye diseases, perhaps leading to the development of drugs and gene therapy to reverse retinal degeneration.

Three categories of retinal degeneration that might benefit from our research—macular degeneration, retinitis pigmentosa and glaucoma—affect millions of people worldwide. Each disease causes problems in different layers of the retina. In macular degeneration, the integrity of the epithelium is impaired by the breakdown of supporting tissue, and this breakdown leads to the deterioration of photoreceptors, particularly in the central region of the retina. In retinitis pigmentosa, the number of the photoreceptors called rods decreases gradually over many years. "Night blindness" appears as the first common symptom. Later, the patient loses most of the visual field except for a small area at the center. Finally, glaucoma damages ganglion cells, which connect the retina to the visual-processing center in the cortex at the back of the brain through projecting optic nerves.

Macular degeneration seems the most amenable of the three to being eased by cell-replacement therapy. Human embryonic stem cells and induced pluripotent stem cells can generate the support tissue, known as retinal pigment epithelium, relatively easily when grown in conventional culture as well as by our method, and cells can be retrieved directly from these cultures. Early small-scale clinical trials with these cells have already started in the U.S., and similar trials are planned in other countries. In these studies, stem cell–derived pigment epithelial cells are injected with a fine needle into the space between the pigment epithelium and photoreceptor layers to replace at least part of the damaged tissue.

Cell therapy for retinitis pigmentosa requires additional technical advances before it can be offered to humans. Our technique, unlike a conventional culture, can generate rod photoreceptors in a cell-dense sheet suitable for transplantation, but we need another critical tool before transplants of such sheets can improve vision. Unlike the simple support tissue of epithelium, photoreceptors need to integrate into the eye's neural circuitry; specifically, they need to reconnect to another type of sensory cell, a bipolar cell, and we do not yet know how to make that linkage happen efficiently. Transplantation of photoreceptors, if successful, would be expected to enable those with even advanced retinitis pigmentosa to recover at least some of their vision.

Glaucoma may be the most difficult of the three diseases to treat through cell therapy. Embryonic stem cell cultures are capable of generating ganglion cells needed for this endeavor. In the postnatal eye, however, optic nerve regrowth is suppressed, and no one has yet figured out how to induce their axons (the branches that send signals into the brain and that form the optic nerve) to reconnect with other cells.

We have learned that embryonic stem cell–derived tissues can do much more than we can currently achieve through artificial tissue engineering in which cells are placed on scaffolds shaped like a layer of skin or a bladder. As researchers, we must humbly and patiently uncover what developing cells can teach us about the intricate processes that lead from a single cell to an organ as complex as the eye. SA

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SCIENTIFIC AMERICAN ONLINE
Read about Sasai and the work of his laboratory in Kobe, Japan, at ScientificAmerican.com/nov2012/sasai

John Carey is a freelance writer and former senior correspondent for *BusinessWeek*, where he covered science, technology, medicine and the environment.

ENVIRONMENT

GLOBAL WARMING: Faster Than Expected?

Loss of ice, melting of permafrost and other climate effects are occurring at an alarming pace

By John Carey

IN BRIEF

Scientists thought that if planetary warming could be kept below two degrees Celsius, perils such as catastrophic sea-level rise could be avoided.

Ongoing data, however, indicate that three global feedback mechanisms may be pushing the earth into a period of rapid climate change even before the two degree C "limit" is reached: meltwater altering ocean circulation; melting permafrost releasing carbon dioxide and methane; and ice disappearing worldwide.

The feedbacks could accelerate warming, alter weather by changing the jet stream, magnify insect infestations and spawn more and larger wildfires.

Photograph by Dan Saelinger

OVER THE PAST DECADE SCIENTISTS THOUGHT THEY HAD FIGURED OUT HOW TO PROTECT humanity from the worst dangers of climate change. Keeping planetary warming below two degrees Celsius (3.6 degrees Fahrenheit) would, it was thought, avoid such perils as catastrophic sea-level rise and searing droughts. Staying below two degrees C would require limiting the level of heat-trapping carbon dioxide in the atmosphere to 450 parts per million (ppm), up from today's 395 ppm and the preindustrial era's 280 ppm.

Now it appears that the assessment was too optimistic. The latest data from across the globe show that the planet is changing faster than expected. More sea ice around the Arctic Ocean is disappearing than had been forecast. Regions of permafrost across Alaska and Siberia are spewing out more methane, the potent greenhouse gas, than models had predicted. Ice shelves in West Antarctica are breaking up more quickly than once thought possible, and the glaciers they held back on adjacent land are sliding faster into the sea. Extreme weather events, such as floods and the heat wave that gripped much of the U.S. in the summer of 2012 are on the rise, too. The conclusion? "As scientists, we cannot say that if we stay below two degrees of warming everything will be fine," says Stefan Rahmstorf, a professor of physics of the oceans at the University of Potsdam in Germany.

The X factors that may be pushing the earth into an era of rapid climate change are long-hypothesized feedback loops that may be starting to kick in. Less sea ice, for example, allows the sun to warm the ocean water more, which melts even more sea ice. Greater permafrost melting puts more CO_2 and methane into the atmosphere, which in turn causes further permafrost melting, and so on.

The potential for faster feedbacks has turned some scientists into vocal Cassandras. Those experts are saying that even if nations do suddenly get serious about reducing greenhouse gas emissions enough to stay under the 450-ppm limit, which seems increasingly unlikely, that could be too little, too late. Unless the world slashes CO_2 levels back to 350 ppm, "we will have started a process that is out of humanity's control," warns James E. Hansen, director of the NASA Goddard Institute for Space Studies. Sea levels might climb as much as five meters this century, he says. That would submerge coastal cities from Miami to Bangkok. Meanwhile increased heat and drought could bring massive famines. "The consequences are almost unthinkable," Hansen continues. We could be on the verge of a rapid, irreversible leap to a much warmer world.

Alarmist? Some scientists say yes. "I don't think that in the near term, catastrophic climate change is in the cards," says Ed Dlugokencky of NOAA, based on his assessment of methane levels. Glaciologist W. Tad Pfeffer of the University of Colorado at Boulder has examined ice loss around the planet and concludes that the maximum conceivable ocean rise this century is less than two meters, not five. Yet he shares Hansen's sense of urgency because even smaller changes can threaten a civilization that has known nothing but a remarkably stable climate. "The public and policy makers should understand how serious a sea-level rise of even 60 to 70 centimeters would be," Pfeffer warns. "These creeping disasters could really wipe us out."

Although scientists may not agree on the pace of climate change, the realization that specific feedback loops may be amplifying the change is causing a profound unease about the planet's future. "We have to start thinking more about the known unknowns and the unknown unknowns," explains Eelco Rohling, a professor of ocean and climate change at the University of Southampton in England. "We might not know exactly what all possible feedbacks are, but past changes demonstrate that they exist." By the time researchers do pin down the unknowns, it may be too late, worries Martin Manning, an atmospheric scientist at Victoria University of Wellington in New Zealand and a key player in the 2007 round of the Intergovernmental Panel on Climate Change (IPCC) reports: "The rate of change this century will be such that we can't wait for the science."

HOT PAST SUGGESTS HOT FUTURE

ONE BIG REASON scientists are becoming increasingly concerned about rapid climate change is improved understanding of our distant past. In the 1980s they were stunned to learn from the record written in ice cores that the planet had repeatedly experienced sudden and dramatic swings in temperature. Since then, they have put together a detailed picture of the past 800,000 years. As Hansen describes in a new analysis, there are remarkably tight correlations among temperature, CO_2 levels and sea levels: they all rise and fall together, almost in lockstep. The correlations do not prove that greenhouse gases caused the warming. New research by Jeremy Shakun of Harvard University and his colleagues, however, points in that direction, showing that the CO_2 jump preceded the temperature jump at the end of the last ice age. They conclude in a recent *Nature* paper that "warming driven by increasing CO_2 concentrations is an explanation for much of the temperature change." (*Scientific American* is part of Nature Publishing Group.)

The feedback scientists fear most is loss of ice, uncovering darker land and seas that absorb solar heat, melting even more ice, amplifying global warming.

Some changes in the past were incredibly rapid. Work on Red Sea sediments by Rohling shows that during the last warm period between ice ages—about 125,000 years ago—sea levels rose and fell by up to two meters within 100 years. "That's ridiculously fast," Rohling says. His analysis indicates that sea levels appear to have been more than six meters higher than they are today—in a climate much like our own. "That doesn't tell you what the future holds, but man, it gets your attention," says Richard Alley, a professor of geosciences at Pennsylvania State University.

Also surprising is how little extra energy, or "forcing," was required to trigger past swings. For instance, 55 million years ago the Arctic was a subtropical paradise, with a balmy average temperature of 23 degrees C (73 degrees F) and crocodiles lurking off Greenland. The tropics may have been too hot for most life. This warm period, dubbed the Paleocene-Eocene Thermal Maximum (PETM), apparently was sparked by a preceding bump of about two degrees C in the planet's temperature, which was already warmer than today. That warming may have caused a rapid release of methane and carbon dioxide, which led to more warming and more emissions of greenhouse gases, amplifying further warming. The eventual result: millions of years of a hothouse earth [see "The Last Great Global Warming," by Lee R. Kump; SCIENTIFIC AMERICAN, July 2011].

In the past 100 years humans have caused a warming blip of more than 0.8 degree C (1.4 degree F). And we are pouring greenhouse gases into the atmosphere 10 times faster than what occurred in the run-up to the PETM, giving the climate a mighty push. "If we spend the next 100 years burning carbon, we are going to take the same kind of leap," says Matthew Huber, a professor of earth and atmospheric sciences at Purdue University.

We are also shoving the climate harder than the known causes of various ice ages did. As Serbian astronomer Milutin Milanković noted nearly 100 years ago, the waxing and waning of ice ages can be linked to small variations in the orbit and tilt of the earth. Over tens of thousands of years the earth's orbit changes shape, from nearly circular to mildly eccentric, because of varying pulls from other planets. These variations alter the solar energy hitting the planet's surface by an average of about 0.25 watt per square meter, Hansen says. That amount is pretty small. To cause the observed swings in climate, this forcing must have been amplified by feedbacks such as changes in sea ice and greenhouse gas emissions. In past warmings, "feedback just follows feedback, follows feedback," says Euan Nisbet, a professor of earth sciences at the Royal Holloway, University of London.

The climate forcing from human emissions of greenhouse gases is much higher—three watts per square meter and climbing. Will the climate thus leap 12 times faster? Not necessarily. "We can't relate the response from the past to the future," Rohling explains. "What we learn are the mechanisms that are in play, how they are triggered and how bad they can get."

TROUBLING FEEDBACKS

THE MOST RAPID of these feedback mechanisms, scientists have figured out, involves ocean currents that carry heat around the globe. If a massive amount of freshwater is dumped into the northern seas—from say, collapsing glaciers or increased precipitation—warm currents can slow or stop, disrupting the engine that drives global ocean currents. That change could turn Greenland from cool to warm within a decade. "Greenland ice-core records show that shifts can occur very, very quickly, even in 10 years," says Pieter Tans, a senior scientist at the NOAA Earth System Research Laboratory.

When the freshwater mechanism became clear by the early 2000s, "a lot of us were really nervous," Alley recalls. Yet more detailed modeling showed that although "adding freshwater is a scary thing, we're not adding it nearly fast enough" to fundamentally alter the planet's climate, he says.

A more immediately worrisome feedback that is beginning to bubble up—literally—involves permafrost. Scientists once thought that organic matter in the tundra extended only a meter deep into the frozen soil—and that it would take a long time for warming to start melting substantial amounts of it deep down. That assessment was wrong, according to new research. "Pretty much everything we've documented has been a surprise," says biologist Ted Schuur of the University of Florida.

The first surprise was that organic carbon exists up to three meters deep—so there is more of it. Plus, Siberia is dotted with giant hills of organic-rich permafrost called yedoma, formed by windblown material from China and Mongolia. Those carbon stores add up to hundreds of billions of metric tons—"roughly double the amount in the atmosphere now," Schuur says. Or as methane hunter Joe von Fischer of Colorado State University puts it: "That carbon is one of the ticking time bombs." More thawing allows more microbes to dine on the organic carbon and turn it into CO_2 and methane, raising temperatures and prompting more thawing.

The ticking may be speeding up. Meltwater on the permafrost surface often forms shallow lakes. Katey Walter Anthony of the University of Alaska Fairbanks has found methane bubbling up from the lake bottoms. Many researchers have also found that permafrost can crack open into mini canyons called thermokarsts, which expose much greater surface area to the air, speeding melting and the release of greenhouse gases. And recent expeditions off Spitsbergen, Norway, and Siberia have detected plumes of methane rising from the ocean floor in shallow waters.

If you extrapolate from these burps of gas to wider regions, the numbers can get big enough to jolt the climate. Yet global measurements of methane do not necessarily show a recent increase. One reason is that hotspots "are still pretty local," says the University of Alaska Fairbanks's Vladimir E. Romanovsky, who charts permafrost temperatures. Another may be that scientists have just gotten better at finding hotspots that have always existed. That is why Dlugokencky says, "I am not concerned about a rapid climate change brought about by a change in methane."

Others are not so sure, especially because there is another potentially major source of methane—tropical wetlands. If rainfall increases in the tropics, which is likely as the atmosphere warms, the wetlands will expand and become more productive, creating more anaerobic decomposition that produces methane. Expanded wetlands could release as much, or more, additional methane as that from Arctic warming. How worried should we be? "We don't know, but we'd better keep looking," Nisbet says.

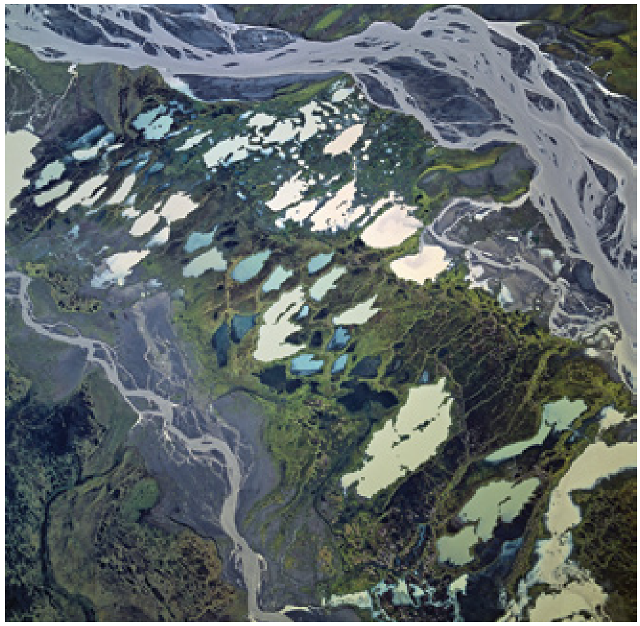
THE ICE EFFECT

THE FEEDBACK that scares many climate scientists the most is a planetary loss of ice. The dramatic shrinking of sea ice in the Arctic Ocean in recent summers, for instance, was not predicted by many climate models. "It is the big failure in modeling," Nisbet says. Ice on Greenland and along Antarctica is disappearing, too.

To figure out what is going on, scientists have been charting glaciers in Greenland by satellite and ground measurement and have been sending probes under the Antarctic ice shelves, "seeing things never seen before," says Jerry Meehl, a senior scientist at the National Center for Atmospheric Research.

On Greenland, glaciologist Sarah Das of the Woods Hole Oceanographic Institution watched as a lake of meltwater suddenly drained through a crack in the 900-meter-thick (3,000-foot-thick) ice. The torrent was powerful enough to lift the massive glacier off the underlying bedrock and increase the speed at which it was sliding into the ocean. In Alaska, Pfeffer has data showing that the huge Columbia Glacier's slide into the sea has accelerated from one meter a day to 15 to 20 meters a day.

In Antarctica and Greenland, large ice shelves that float on ocean water along the coast are collapsing—a wake-up call about how unstable they are. Warmer ocean waters are eating away at the ice shelves from below while warmer air is opening cracks from above. The ice shelves act as buttresses, holding back ice that is grounded on the ocean bottom and adjacent glaciers on land from slinking into the sea under gravity's relentless pull. Although the loss of floating ice does not raise sea levels, the submerging glaciers do. "We're now working hard to find out whether sea-level rise could be remarkably faster than expected," Alley says.



RAPID CHANGE: Feedback mechanisms could be speeding up global warming: thawing permafrost, like that in central Iceland (*left*); retreating glaciers such as Trift in the Swiss Alps (*center*), which has receded three kilometers; and melting ice that spills into the sea, seen in Spitsbergen, Norway (*right*).

BERNHARD EDMAIER *Photo Researchers, Inc.*

Ice loss is feared not just because of sea-level rise but also because it kicks off a powerful feedback mechanism. Ice reflects sunlight back to space. Take it away, and the much darker land and seas absorb more solar heat, melting more ice. This change in the albedo (reflectivity) of the earth's surface can explain how small forcings in the paleoclimate record could be amplified, Hansen says, "and the same will occur today."

So far only a few scientists are willing to go as far as Hansen in predicting that the oceans could rise by as much as five meters by 2100. "But we don't really know," Alley says. "I'm still guessing that the odds are in my favor [in expecting a smaller rise], but I would hate for anyone to buy coastal property based on anything I said."

FOREST FOR THE TREES

THE FLUCTUATIONS in the earth's past climate make it clear that feedbacks will dramatically transform the planet now if we push hard enough. "If we burn all the carbon we have access to, we're pretty much guaranteed of having a PETM-like warming," Huber says. Good for Arctic crocodiles, perhaps, but not for humans or most ecosystems.

Yet what really keeps scientists up at night is the possibility that even if these particular feedbacks do not bring near-term threats to humanity, they could drive other mechanisms that do. A prime candidate is the planet's water, or hydrological, cycle. Each year brings additional evidence that climate change is causing more extreme weather events such as floods and droughts while fundamentally altering regional climates.

A recent analysis by Rahmstorf shows that heat waves like the one that devastated Russia in 2010 are five times more likely because of the warming that has already occurred—"a massive

JAMES BALOG *Extreme Ice Survey* (left); JAN TOVE JOHANSSON *Getty Images* (right)

factor," he says. And new work pins the record-breaking warm 2011–2012 U.S. winter (and record-breaking cold spell in Europe that same season) on the loss of Arctic sea ice. One suggested mechanism: with less sea ice, more Arctic water warms. The ocean releases that extensive heat in the autumn, altering pressure gradients in the atmosphere, which creates bigger bends in the jet stream that can get stuck in place for longer periods. Those bends can bask the U.S. Northeast in winter warmth while locking eastern Europe in a deep freeze.

Making this story even more complex is the potential for ecological feedbacks. Warmer temperatures in the western U.S. and Canada, for instance, have helped unleash an epidemic of mountain pine beetles. The insects have killed hundreds of thousands of hectares of trees, threatening to turn forests from carbon sinks (healthy trees absorbing CO_2) into carbon sources (dead trees decomposing). A hot spell in 2007 set the stage for the first fire on the North Slope's tundra in 7,000 years, accelerating permafrost melting and its carbon emissions in that area. Warming in Siberia is starting to transform vast forests of larches into spruce and fir woodlands. Larches drop their needlelike leaves in winter, thereby allowing the sun's heat to reflect off the snow cover and return to space. Spruces and firs keep their needles, absorbing the solar heat before it can reach the snow, explains ecologist Hank Shugart of the University of Virginia. Feedbacks from vegetation changes alone could give the planet a 1.5 degree C kick, he estimates: "We're playing with a loaded gun here."

Nisbet's own "nightmare scenario" starts with a blip in methane emissions and a very warm summer that leads to massive fires, pouring carbon into the atmosphere. The smoke and smog blanket Central Asia and weaken the monsoons, causing widespread crop failures in China and India. Meanwhile a large El Niño pattern of unusually warm water in the tropical Pacific brings drought to the Amazon and Indonesia. The tropical forests and peatlands also catch fire, injecting even more CO_2 into the atmosphere and putting the climate on the fast track to rapid warming. "It's a feasible scenario," Nisbet observes. "We may be more fragile than we think we are."

But just how powerful could the various feedback loops become? Climate models, which are good at explaining the past and present, stumble when it comes to predicting the future. "People can conceptualize these abrupt changes better than the models do," Schuur says. Even if the planet is in a tipping point now, he adds, we may not recognize it.

The unsettling conclusion for climate policy is that science does not have definitive answers. "We know the direction but not the rate," Manning says. Yet the uncertainties do not justify inaction, scientists insist. On the contrary, the uncertainties bolster the case for an immediate worldwide effort to reduce greenhouse gas emissions because they reveal how substantial the risks of rapid change really are. "What we're doing at the moment is an experiment comparable on a geological scale to the big events of the past, so we would expect the inputs to have consequences similar to those in the past," Nisbet says.

That is why Hansen cannot look at his grandchildren and not become an activist on their behalf. "It would be immoral," he says, "to leave these young people with a climate system spiraling out of control." SA

MORE TO EXPLORE

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Video by Katey Walter Anthony of the University of Alaska Fairbanks of methane—from melting permafrost—catching fire: **www.youtube.com/watch?v=YegdEOSQotE**

SCIENTIFIC AMERICAN ONLINE
For a slide show of images showing climate feedbacks and the ecological feedback mechanisms they can cause, visit **ScientificAmerican.com/nov2012/climate-change**

PALEONTOLOGY

THE STRANGEST BIRD

Recent fossil discoveries reveal the surprising evolutionary history of penguins

By R. Ewan Fordyce and Daniel T. Ksepka

NOVEMBER IN ANTARCTICA, AND THE ICE is on the wane. Soon the emperors will go fishing. They'll spend the austral summer gliding through the frigid Southern Ocean, diving to depths of more than 1,500 feet in search of fish, squid and krill to gorge on before making the long trek inland for the winter to breed. When the time comes to haul out, they will launch themselves out of the water back onto the ice. That brief moment between sea and ice is the only time these penguins experience what most birds take for granted: being airborne.

Indeed, emperors and other penguins are bizarre birds. Like all birds, they possess feathers, wings and beaks and lay eggs. But penguins also exhibit a suite of characteristics that readily distinguishes them from their feathered friends. Their wings have evolved into flippers for swimming; their trademark tuxedo camouflages them from predators above and below; their dense

IN BRIEF

Penguins are weird birds in that they cannot fly and are instead proficient swimmers and divers.

Evolutionary biologists have long wondered how penguins evolved their peculiar traits and how some of their kind conquered the bitterly cold Antarctic.

Recent fossil discoveries have enabled researchers to piece together the penguins' evolutionary past, revealing that some of the traits that fortify them against the cold evolved under warm conditions.

Although penguins have triumphed over 60 million years of climate change, current warming conditions may outpace their ability to adapt.

bones provide ballast for diving; their short, thick legs steer their body underwater and help give them that endearing (and energetically efficient) waddle on land. Thanks to these traits and others, penguins are masters of the marine realm, and many of their kind—the emperors among them—have managed to conquer one of the most extreme environments on the planet.

Paleontologists have long wondered whence these peculiar birds originated and how they spread across the Southern Hemisphere. Fossil discoveries made over the past decade have helped reconstruct the penguin's evolutionary march. It turns out that many of their signature features arose under far balmier conditions than the brutally cold settings that people tend to imagine when they think of penguins. Yet that history does not improve the odds that penguins will survive in the face of future warming. The new findings make clear that the biology and geographic distribution of these birds reflect a complex interplay of continental drift, shifting climate and natural selection over tens of millions of years—underscoring the vulnerability of today's penguins to the effects of rapid climate change.

R. Ewan Fordyce is a vertebrate paleontologist at the University of Otago in New Zealand. His fieldwork and research center on the fossil marine vertebrates of New Zealand, including penguins and whales.

Daniel T. Ksepka is a vertebrate paleontologist at North Carolina State University. One of his main research interests is reconstructing the evolution of penguins from their flying ancestors.

ANCIENT ORIGIN

SCIENTISTS HAVE KNOWN about fossil penguins for more than 150 years, but the remains they recovered early on were mere scraps that held little information about the birds they came from. The very first penguin fossil to be identified was a single bone collected from New Zealand limestone by an unknown Maori. The fossil ended up with English anatomist Thomas Henry Huxley. Huxley identified the scrap as the anklebone of an extinct penguin larger than an emperor, which at three feet tall and 90 pounds is the largest of today's penguin species. He dubbed the fossil penguin *Palaeeudyptes antarcticus,* meaning "ancient good diver of the South." In the decades that followed, more remains of giant penguins came to light in New Zealand and beyond. But like the anklebone Huxley diagnosed, they were all fragmentary and hard to interpret. Scientists were left puzzling over how these giants lived, why they went extinct and where they fit in the bigger picture of penguin evolution.

The fossil record of penguins began to improve in the late 1970s, when one of us (Fordyce) came across a broken leg bone poking out of a sandstone cliff face near Waimate in southern New Zealand. Carefully chipping away at the surrounding rock, Fordyce found more bones of a large penguin that lived 27 million years ago. That partial skeleton provided new insight into the body plan of ancient penguins, but it was still too advanced to reveal their origins. It was not until the 1980s and 1990s that fossils fitting that bill came to light, when several specimens revealing the earliest known stages of penguin evolution turned up in the Waipara area of New Zealand. These remains, which date to between 62 million and 58 million years ago, show that early penguins superficially resembled cormorants, with their long, narrow beak and flexible wings. Yet on closer inspection, they were developing classic penguin traits. For example, their upper wing bones were flat and wide like those of modern penguins, their anklebone was short and broad, and their bones overall were denser than those of flying birds.

After analyzing these protopenguin fossils, Fordyce, Tatsuro Ando, then his graduate student at the University of Otago in New Zealand, and Craig Jones of GNS Science assigned them to two species of a new genus, *Waimanu,* meaning "water bird" in the Maori language. In life, the larger species, *Waimanu manneringi,* approached the size of the emperor penguin at about three feet tall, whereas *Waimanu tuatahi* probably stood roughly two and a half feet tall, a bit bigger than the modern day yellow-eyed penguin. Neither seems likely to have been able to fly in the air—both excelled instead at propelling themselves through the water.

Waimanu penguins are the oldest and most archaic penguins known. They are also some of the oldest representatives of any modern bird lineage. These penguins lived shortly after the catastrophic event that ended the Cretaceous period 65 million years ago and that doomed the dinosaurs and many other creatures. Some experts have suggested that the event eliminated almost all birds, with perhaps just a handful of lineages surviving. Such a scenario would imply that the penguin lineage and other modern bird lineages evolved rapidly from a single ancestral stock in the few million years following the mass extinction. Based on the available evidence from fossils and DNA analyses of modern birds, we think a more plausible explanation is that many modern bird lineages—including the penguin line—originated before that epic disaster struck and somehow managed to hang on when their dinosaur brethren could not.

That the earliest penguins have turned up in New Zealand is probably no coincidence. Many penguins today live around the country's coasts. Until humans arrived, less than 1,000 years ago, the islands there formed a temperate seabird paradise on the margins of the South Pacific and Southern oceans. The region was free of terrestrial predatory mammals and afforded space for breeding colonies, with abundant food in the surrounding seas.

Geologic evidence suggests that the area would have been equally conducive to the seabird way of life at the end of the Cretaceous, when penguins presumably got their start—albeit for somewhat different reasons. New Zealand today is the largest exposed area of a submerged mini continent known as Zealandia that broke off from the ancient supercontinent of Gondwana perhaps 85 million years ago. Thus liberated, Zealandia drifted northeast into the Pacific, carrying plants and animals, including dinosaurs, to its resting spot about halfway between the South Pole and tropics. As Zealandia drifted, it cooled and sank. Shallow seas flooded the land, and a broad continental shelf formed around its perimeter. Despite its isolation from other landmasses, Zealandia did not emerge from the end-Cretaceous extinction unscathed. Many of its marine and terrestrial organisms perished in that die-off. Yet what was bad for those creatures was good for penguins. With marine reptiles such as mosasaurs and plesiosaurs out of the picture, early penguins could swim the waters around Zealandia free of competition or predation.

PRECEDING PAGES: FRANS LANTING; THIS PAGE: SOURCE: MARILYN A. FORDYCE (*Fordyce*)

BREAKTHROUGH ADAPTATION

HAVING GOTTEN THEIR sea legs in Zealandia, penguins soon expanded their domain dramatically, dispersing across thousands of miles and into new climate zones. Fossils of *Perudyptes devriesi* from Peru show that penguins arrived close to the equator about 42 million years ago, settling in one of the hottest places on earth during one of the hottest times in the planet's history. Back then, the temperature in Peru was 86 degrees Fahrenheit or so, and average global sea temperature was 10.8 to 14.4 degrees F higher than it is today. Giant penguins such as *Anthropornis nordenskjoeldi* waddled onshore at Seymour Island in Antarctica around the same time. By 37 million years ago the birds had spread to almost every major landmass in the Southern Hemisphere.

Yet why, after restricting themselves to Zealandia for millions of years, did penguins suddenly start spreading across the Southern Hemisphere around 50 million years ago? Recently one of us (Ksepka) discovered an important clue to this mystery: a long-overlooked feature on the surface of fossil flipper bones. The humerus bears a series of grooves that are easy to miss among the markings associated with tendons and muscles. Ksepka first noticed the grooves in 2006 while studying the flippers of frozen penguins in the basement of the American Museum of Natural History in New York City in an attempt to figure out the relations between the markings on fossil bones and the soft anatomy of the flipper. At the same time, fellow penguin researcher Daniel Thomas was conducting similar investigations at the University of Otago with an eye toward figuring out how the penguins' ability to regulate their body temperature evolved.

As stewards of modern avian diversity, we can learn conservation lessons from the fossil record of penguins.

In comparing notes, Ksepka and Thomas realized that those grooves form at the spot where a cluster of arteries and veins presses against the humerus. These blood vessels make up a countercurrent heat exchanger called the humeral arterial plexus, which allows penguins to limit heat loss through the flippers and to maintain their core body temperature in cold water. In live penguins, hot blood leaving the heart gets cooled by the plexus before reaching the flipper tip, and cold blood returning from the flipper gets warmed before approaching the heart.

The identity of the grooves on the fossil flipper bones shed some surprising light on the origin of penguin thermoregulation. One of the most amazing aspects of modern penguin biology is the birds' ability to tolerate extreme cold. One would logically assume that the plexus evolved as an adaptation to frigid environments. But fossils suggest otherwise. Penguins such as the modest-sized *Delphinornis* from Antarctica show that this feature evolved at least 49 million years ago. The early *Waimanu* penguins from Zealandia show no hint of the trait at 58 million years ago, however. The plexus therefore must have evolved in the intervening time, when the earth was far warmer than it is today. Back then, Antarctica lacked permanent ice sheets and instead offered a temperate forested environment; Zealandia was even toastier.

What use did early penguins have for a heat-conserving plexus in this greenhouse world? Although sea-surface temperatures were high, early penguins probably foraged in cool upwelling regions, which are rich in nutrients and thus support a bounty of prey, including fish and squid. The plentiful food available in these waters comes with a risk, however. Because heat is lost more quickly in water than air, a warm-blooded animal—such as a human diver—can go into hypothermia even in warm seas if the water is below core body temperature. Warm-blooded penguins risked suffering the same fate in those cool upwellings—even with their insulating layers of fat and waterproofing feathers. Reducing heat loss through the flipper would have helped them conserve body heat on long foraging swims in chilly waters.

The humeral plexus may have also allowed penguins to survive the long open-water journeys by which they initially dispersed from Zealandia to other continents. We make that conjecture because the first waves of fossil penguins that show up outside Zealandia all appear to have the feature. Only much later would modern penguins co-opt this mechanism to invade the sea ice shelves that formed when the planet cooled.

VARIATIONS ON A THEME

AS PENGUINS SPREAD throughout the southern oceans, they underwent a remarkable radiation, evolving a huge diversity of forms. For one, New Zealand's *Pachydyptes ponderosus* ("stout diver") was a true giant, known only from a handful of thick bones dating to around 35 million years ago. Paleontologists have estimated the mass of this penguin at upward of 150 pounds. Imagine the splash from such a bird plunging into the water from a rocky perch! At the other end of the spectrum, 21-million-year-old *Eretiscus tonnii* ("tiny rower") from Argentina stood a mere one and a half feet tall. Perhaps like the living little blue penguin from New Zealand, members of this species came onshore in rafts composed of dozens of birds—a behavior that may reduce predation risk.

Some penguins carried extra-deadly weaponry. About 36 million years ago *Icadyptes* ("Ica's diver," named for a region of Peru) *salasi* patrolled prehistoric seaways equipped with a hyperelongated, reinforced beak mounted on a neck wrapped in strong muscles, ready to impale a passing fish or squid. Other penguins sported strange cloaks. Ksepka vividly recalls a night in Lima, when Julia Clarke of the University of Texas at Austin cleared away the rock concealing a beautifully preserved specimen of *Inkayacu paracasensis* ("water king") and exposed its 36-million-year-old feathers and skin—a once-in-a-lifetime find. Microscopic details later revealed evidence for reddish brown and gray pigments, indicating a striking departure from the traditional black-and-white tuxedo patterns of modern penguins.

Not only did ancient penguins evolve diverse forms, they evolved many of them. Scientists have named more than 50 fossil species in addition to the 19 extant species, and in numerous areas we have solid evidence that multiple penguin species lived together in the past. On Seymour Island, for instance, as many as 10 species occur in the same fossil beds. This overlap is fascinating because it suggests these species were able to carve out enough unique ecological niches from the same physical space to coexist. (By comparison, among modern penguins no more than five species share the same breeding ground.)

Ancient penguins succeeded in cohabiting, in part, by having a larger range of sizes than modern penguins display, which brings us back to those enigmatic giants from New Zealand. Working with Ando and Jones, we recently completed an in-depth study of some 27-million-year-old specimens, including the partial skeleton Fordyce found in the 1970s. Although they resemble Huxley's *Palaeeudyptes,* the fossils constitute a new genus, which we named *Kairuku*—Maori for "the diver that returns with food." The preservation of all the key bones in the skeleton allowed us to reconstruct the body size and proportions. Standing an estimated four feet, four inches tall and tipping the scales at 135 pounds or more, *Kairuku* penguins would have dwarfed today's emperors.

We think the size of these ancient New Zealand penguins was an adaptation for swimming long distances, from rookeries on the low islands of Zealandia out to the edge of the continental shelf. Large body size would have also allowed for efficient diving into deep water to search for prey such as squid because larger birds can swim more rapidly, store more oxygen for long dives and conserve body heat more efficiently. Presumably the larger fossil penguins on Seymour Island were likewise able to swim farther and deeper to hunt, whereas the smaller species foraged closer to land.

AN UNCERTAIN FUTURE

AS STEWARDS of modern avian diversity, we can learn conservation lessons from the fossil record of penguins. Most of the penguin extinctions that have taken place over the past 60 million years occurred long before humans appeared. *Homo sapiens* is not completely innocent, however. At least one penguin species—a relative of the yellow-eyed penguin known as *Megadyptes waitaha*—appears to have gone extinct, at least in part, as a result of human hunting. Although penguins are almost never intentionally hunted today, they remain under threat from both local and global forces, including overfishing, oil spills and introduced predators. Yet perhaps more troubling than these forces in the long run is the threat posed by climate change.

Penguins have done a remarkable job of adapting to dramatic shifts in climate. They have thrived both in the steamy equatorial zones of the earth during a greenhouse phase and in the ice-bound wastelands of modern Antarctica. We might mistake the success of penguins over the past 60 million years of climatic shifts for resilience against anything global warming can throw at them. This mistake would be grave, though. When it comes to adapting to climate change, tempo is critical. Paleontologists have found evidence that many species moved their ranges gradually during major prehistoric climate shifts, such as those that accompanied advancing and retreating glaciers in the past few hundred thousand years of ice age interglacial cycles.

FINDINGS

A Panoply of Penguins

Fossil discoveries and analyses of DNA from modern-day penguins suggest that this distinctive group of birds got its start while dinosaurs still roamed the earth. The oldest known fossil penguins hail from what is now New Zealand and date to between 62 million and 58 million years ago. The catastrophic event that extinguished the dinosaurs and other terrestrial and marine predators allowed penguins to thrive in the balmy waters around the submerged mini continent of Zealandia. Then, around 50 million years ago, penguins suddenly started spreading across the Southern Hemisphere, probably thanks to a key evolutionary innovation: a countercurrent heat exchanger called the humeral arterial plexus that helped the birds maintain core body temperature in cool water. As penguins dispersed, they evolved a tremendous diversity of sizes and shapes—much more than modern penguins exhibit. The evolutionary tree at the bottom right shows the relations of a number of penguin species.

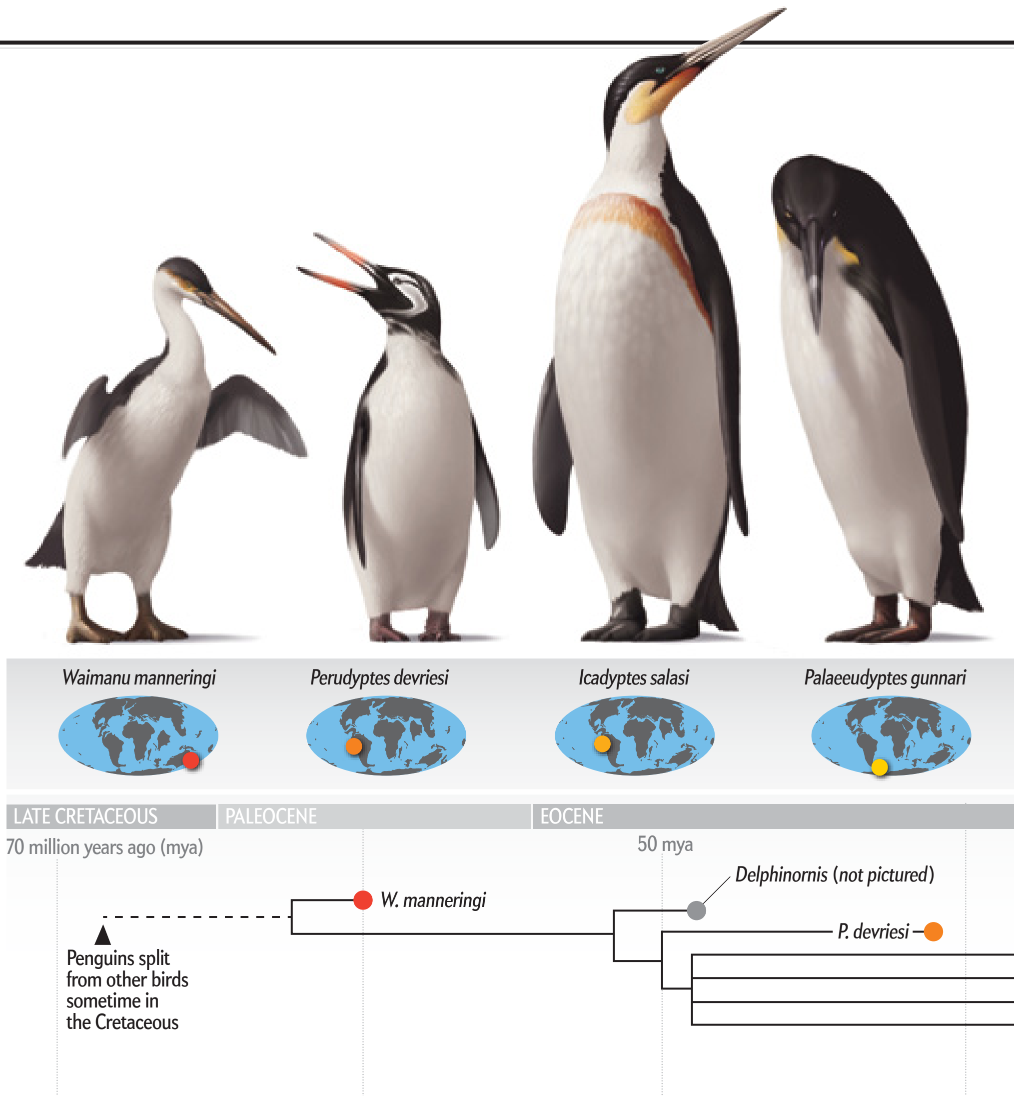


Illustration by Stephanie Abramowicz, Maps by XNR Productions

Some species respond very slowly, which is fine when climate is warming a few degrees over the course of a few million years. Yet if temperatures climb several degrees over the course of a few decades, as many models predict could happen, species may not have time to relocate to more suitable habitats. Or there may be no suitable habitats to which to move.

Consider the Galápagos penguin. This small bird generally flourishes in the equatorial sunshine but suffers severe population drops during strong El Niño years, when Pacific Ocean currents are disrupted and the cold, food-rich waters that usually envelop the islands are replaced with warmer, nutrient-depleted ones. Because these penguins do not stray far from their home islands, they will literally have nowhere to go if warming makes the Galápagos Islands unsuitably hot for raising chicks or catching food.

Emperor penguins, for their part, face a different challenge. These birds may never set foot on dry land throughout their lives, breeding as they do on thick sheets of sea ice. If ice sheets melt too soon in the year, breeding colonies may be destroyed. The penguins' allegiance to their colonies magnifies this danger: many individuals return to the same exact location to breed, year after year, so the seemingly simple solution of moving to a new patch of ice may not be viable, because their breeding behavior is so deeply ingrained.

As paleontologists, we are increasingly aware of the fragility of modern penguins. Penguins today are less diverse in their morphology and more restricted in their ecological roles, and fewer species of them exist today than was true millions of years ago. Although biologists think of them as quintessentially modern birds, in many ways living penguins are survivors of a great dynasty that has yielded some of the most interesting animals ever to have roamed land or sea. What a tragedy it would be if these extraordinary creatures perished on our watch. SA

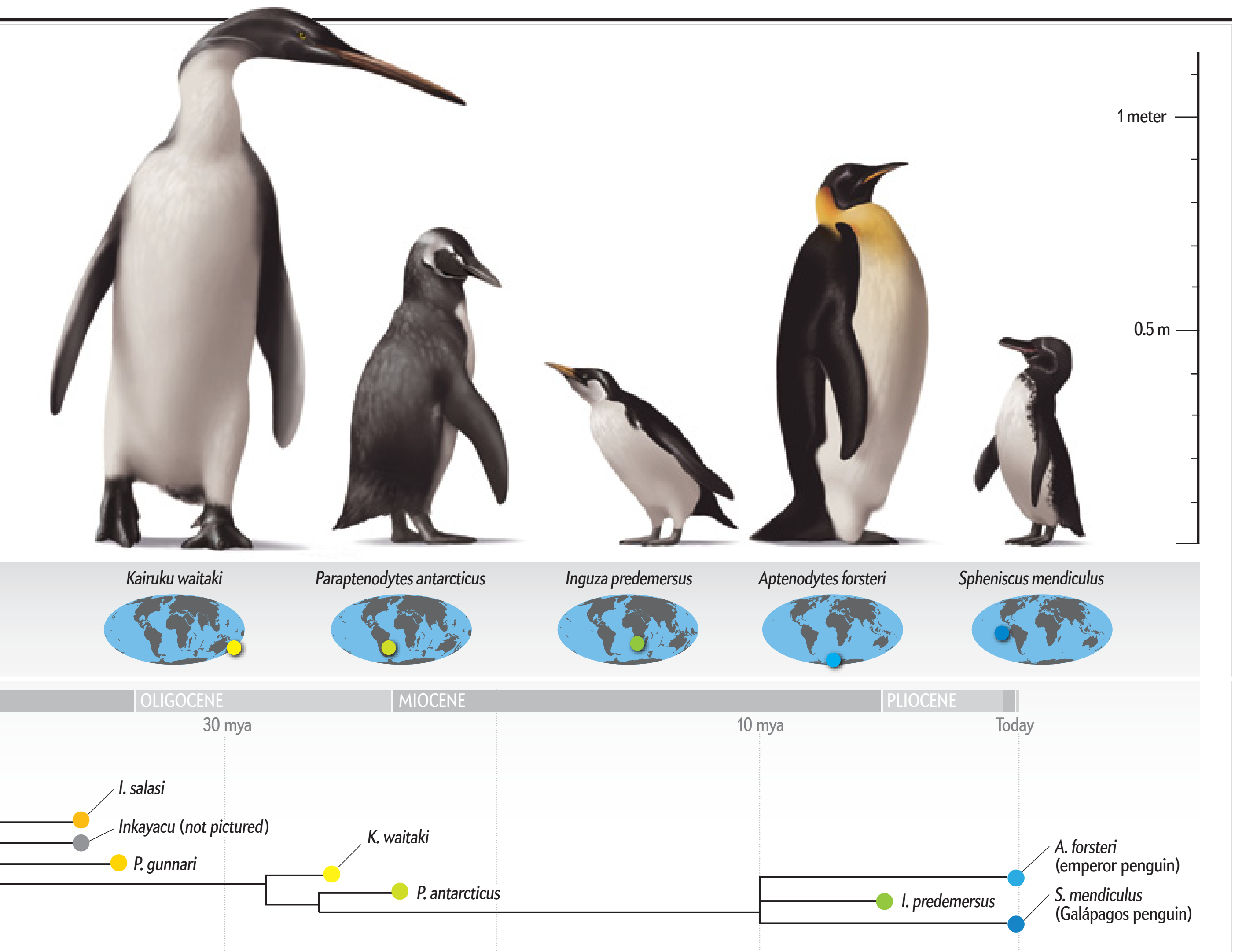
MORE TO EXPLORE

Penguin Heat-Retention Structures Evolved in a Greenhouse Earth. Daniel B. Thomas, Daniel T. Ksepka and R. Ewan Fordyce in *Biology Letters,* Vol. 7, No. 3, pages 461–464; June 23, 2011.

New Fossil Penguins (Aves, Sphenisciformes) from the Oligocene of New Zealand Reveal the Skeletal Plan of Stem Penguins. Daniel T. Ksepka et al. in *Journal of Vertebrate Paleontology,* Vol. 32, No. 2, pages 235–254; March 2012.

March of the Fossil Penguins (blog): **http://fossilpenguins.wordpress.com**

SCIENTIFIC AMERICAN ONLINE
View a slide show of modern penguins at **ScientificAmerican.com/nov2012/penguins**

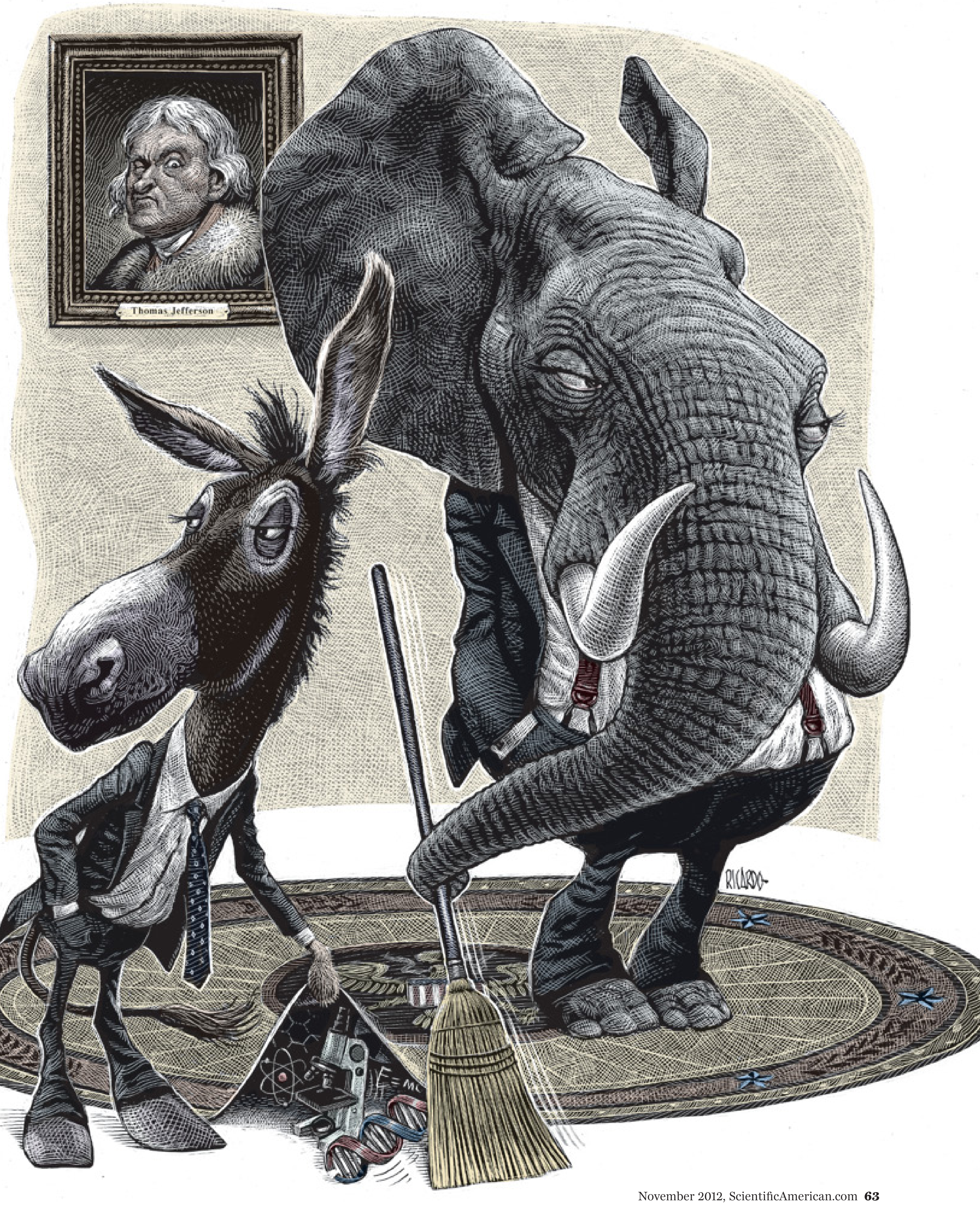


AMERICA'S SCIENCE PROBLEM

THE UNITED STATES FACED DOWN *AUTHORITARIAN GOVERNMENTS* **on the left and right.** **Now it may be facing an even greater challenge** **FROM WITHIN**

By SHAWN LAWRENCE OTTO

Illustration by Ricardo Martinez


Thomas Jefferson
RICARDO

Shawn Lawrence Otto is co-founder of ScienceDebate.org and author of *Fool Me Twice: Fighting the Assault on Science in America.* He is recipient of IEEE-USA's Award for Distinguished Public Service and writes for the Huffington Post and blogs at Neorenaissance.org.

IT IS HARD TO KNOW EXACTLY WHEN IT BECAME ACCEPTABLE FOR U.S. POLITICIANS TO BE ANTIscience. For some two centuries science was a preeminent force in American politics, and scientific innovation has been the leading driver of U.S. economic growth since World War II. Kids in the 1960s gathered in school cafeterias to watch moon launches and landings on televisions wheeled in on carts. Breakthroughs in the 1970s and 1980s sparked the computer revolution and a new information economy. Advances in biology, based on evolutionary theory, created the biotech industry. New research in genetics is poised to transform the understanding of disease and the practice of medicine, agriculture and other fields.

The Founding Fathers were science enthusiasts. Thomas Jefferson, a lawyer and scientist, built the primary justification for the nation's independence on the thinking of Isaac Newton, Francis Bacon and John Locke—the creators of physics, inductive reasoning and empiricism. He called them his "trinity of three greatest men." If *anyone* can discover the truth by using reason and science, Jefferson reasoned, then *no one* is naturally closer to the truth than anyone else. Consequently, those in positions of authority do not have the right to impose their beliefs on other people. The people themselves retain this inalienable right. Based on this foundation of science—of knowledge gained by systematic study and testing instead of by the assertions of ideology—the argument for a new, democratic form of government was self-evident.

Yet despite its history and today's unprecedented riches from science, the U.S. has begun to slip off of its science foundation. Indeed, in this election cycle, some 236 years after Jefferson penned the Declaration of Independence, several major party contenders for political office took positions that can only be described as "antiscience": against evolution, human-induced climate change, vaccines, stem cell research, and more. A former Republican governor even warned that his own political party was in danger of becoming "the antiscience party."

Such positions could typically be dismissed as nothing more than election-year posturing except that they reflect an anti-intellectual conformity that is gaining strength in the U.S. at precisely the moment that most of the important opportunities for economic growth, and serious threats to the well-being of the nation, require a better grasp of scientific issues. By turning public opinion away from the antiauthoritarian principles of the nation's founders, the new science denialism is creating an existential crisis like few the country has faced before.

In late 2007 growing concern over this trend led six of us to try to do something about it. Physicist Lawrence M. Krauss, science writer and film director Matthew Chapman (who is Charles Darwin's great–great-grandson), science philosopher Austin Dacey, science writer Chris Mooney, marine biologist Sheril Kirshenbaum and I decided to push for a presidential science debate. We put up a Web site and began reaching out to scientists and engineers. Within weeks 38,000 had signed on, including the heads of several large corporations, a few members of Congress from both parties, dozens of Nobel laureates, many of the nation's leading universities and almost every major science organization. Although presidential hopefuls Barack Obama and John McCain both declined a debate on scientific issues, they provided written answers to the 14 questions we asked, which were read by millions of voters.

In 2012 we developed a similar list, called "The Top American Science Questions," that candidates for public office should be answering [see "Science in an Election Year," starting on page 66, for a report card by *Scientific American*'s editors measuring how President Obama and Governor Mitt Romney did]. The presidential candidates' complete answers, as well as the responses provided by key congressional leaders to a subset of those questions, can be found at www.ScientificAmerican.com/nov2012/science-

IN BRIEF

A large number of major party contenders for political office this year took antiscience positions against evolution, human-induced climate change, vaccines, stem cell research, and more.

Such positions are surprising because the economy is such a big factor in this election, and half the economic growth since World War II can be traced to innovations in science and technology.

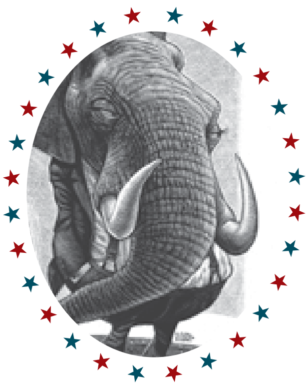
Partisans at both ends of the political spectrum have been guilty of science denialism. But the Republican version is particularly dangerous because it attacks the validity of science itself.

U.S. voters must push candidates and elected officials to express their views on the major science questions facing the nation or risk losing out to those countries with reality-based policies.

debate and at www.sciencedebate.org/debate12.

These efforts try to address the problem, but a larger question remains: What has turned so many Americans against science—the very tool that has transformed the quality and quantity of their lives?

Science denialism among Democrats includes the false belief that vaccines cause autism. Republican science denialism falsely denies climate change and evolutionary biology.



A CALL TO REASON

TODAY'S DENIAL of inconvenient science comes from partisans on both ends of the political spectrum. Science denialism among Democrats tends to be motivated by unsupported suspicions of hidden dangers to health and the environment. Common examples include the belief that cell phones cause brain cancer (high school physics shows why this is impossible) or that vaccines cause autism (science has shown no link whatsoever). Republican science denialism tends to be motivated by antiregulatory fervor and fundamentalist concerns over control of the reproductive cycle. Examples are the conviction that global warming is a hoax (billions of measurements show it is a fact) or that we should "teach the controversy" to schoolchildren over whether life on the planet was shaped by evolution over millions of years or an intelligent designer over thousands of years (scientists agree evolution is real). Of these two forms of science denialism, the Republican version is more dangerous because the party has taken to attacking the validity of science itself as a basis for public policy when science disagrees with its ideology.

It gives me no pleasure to say this. My family founded the Minnesota Republican Party. But much of the Republican Party has adopted an authoritarian approach that demands ideological conformity, even when contradicted by scientific evidence, and ostracizes those who do not conform. It may work well for uniform messaging, but in the end it drives diverse thinkers away—and thinkers are what we need to solve today's complex problems.

This process has left a large, silent body of voters who are fiscally conservative, who believe in science and evidence-based policies, and who are socially tolerant but who have left the party. In addition, Republican attacks on settled scientific issues—such as anthropogenic climate change and evolution—have too often been met with silence or, worse, appeasement by Democrats.

Governor Romney's path to endorsement exemplifies the problem. "I don't speak for the scientific community, of course, but I believe the world is getting warmer," Romney told voters in June 2011 at a town hall meeting after announcing his candidacy. "I can't prove that, but I believe based on what I read that the world is getting warmer, and number two, I believe that humans contribute to that." Four days later radio commentator Rush Limbaugh blasted Romney on his show, saying, "Bye-bye nomination. Bye-bye nomination, another one down. We're in the midst here of discovering that this is all a hoax. The last year has established that the whole premise of man-made global warming is a hoax! And we still have presidential candidates who want to buy into it."

By October 2011 Romney had done an about-face. "My view is that we don't know what's causing climate change on this planet, and the idea of spending trillions and trillions of dollars to try and reduce CO_2 emissions is not the right course for us," he told an audience in Pittsburgh, then advocated for aggressive oil drilling. And on the day after the Republican National Convention, he tacked back toward his June 2011 position when he submitted his answers to ScienceDebate.org.

Romney is not alone in appreciating the political necessity of embracing antiscience views. House Speaker John A. Boehner, who controls the flow of much legislation through Congress, once argued for teaching creationism in science classes and asserted on national television that climate scientists are suggesting that carbon dioxide is a carcinogen. They are not. Representative Michele Bachmann of Minnesota warned in 2011 during a Florida presidential primary debate that "innocent little 12-year-old girls" were being "forced to have a government injection" to prevent infection with human papillomavirus (HPV) and later said the vaccine caused "mental retardation." HPV vaccine prevents the main cause of cervical cancer. Religious conservatives believe this encourages promiscuity. There is no evidence of a link to mental retardation.

In a separate debate, Republican candidate Jon Huntsman was asked about comments he had made that the Republican Party is becoming the antiscience party. "All I'm saying," he replied, "is that for the Republican Party to win, we can't run from science." Republican primary voters apparently disagreed. Huntsman, the lone candidate to actively embrace science, finished last in the polls.

In fact, candidates who began to lag in the GOP presidential primaries would often make antiscience statements and would subsequently rise in the polls. Herman Cain, who is well respected in business circles, told voters that "global warming is poppycock." Newt Gingrich, who supported doubling the budget of the National Institutes of Health and who is also a supporter of ScienceDebate.org, began describing stem cell research as "killing children in order to get research material." Candidates Rick Perry and Ron Paul both called climate change "a hoax." In February, Rick Santorum railed that the left brands Republicans as the antiscience party. "No. No, we're not," he announced. "We're the truth party."

Antiscience reproductive politics surfaced again in August, this time in one of the most contested U.S. Senate races. Todd

Continued on page 70

Science in an Election Year

Scientific American rates the candidates' answers to 14 science questions

MORE THAN A DOZEN science and engineering organizations worked with ScienceDebate.org to draft 14 top science questions to ask the two main presidential candidates this election year. Although President Barack Obama and Governor Mitt Romney declined to debate these issues in person (at least as of press time), their campaigns provided written responses to the queries.

Because these are substantive issues that will play a critical role in determining the nation's—not to mention our planet's—future, the *Scientific American* editors summarized and rated the candidates' answers. Our following analysis is not a comprehensive guide to the election—you will have to look elsewhere for an evaluation of the candidates' positions on foreign affairs, social values or tax policy. Instead we focused on highlighting how the candidates differ from each other on science.

To make our determination, we invited readers to send us leads and solicited input from our board of advisers and other subject-matter experts. We scored the candidates' answers on a five-point scale (with five being best), using the following criteria: how directly and completely they answered the question; scientific accuracy; feasibility (including economic viability and clear accounting for both revenues and costs); potential benefits to health, education and the environment; and sustainability (meaning how well the proposed solutions balance the needs of current and future generations).

Overall, we found that Romney was more specific about what he would like to do in the next four years than Obama. His responses also fared better on feasibility. Obama had the upper hand on scientific accuracy. Romney's answers on climate change, ocean health and freshwater, in particular, revealed an unfamiliarity with the evidence that shows how urgent these issues have become. In a few cases, the candidates received identical scores for different reasons.

What follows is a summary. The candidates' full responses can be found at www.ScientificAmerican.com/nov2012/candidates or at www.sciencedebate.org/debate12.

—The Editors

INNOVATION AND THE ECONOMY

Science and technology have been responsible for half the growth of the U.S. economy since World War II, when the federal government first prioritized peacetime science mobilization. Yet several recent reports question the U.S.'s continued leadership in these vital areas. What policies will best ensure that America remains a world leader in innovation?

4 **ROMNEY** offers a number of specific proposals. He would raise visa caps for highly skilled foreign workers, promote free-trade agreements with "nations committed to the principles of free enterprise," require that all "major" regulations receive congressional approval and set a "cap" on regulations. He also promotes lower corporate taxes and a stronger tax credit for R&D spending. Regarding federal research funding, he criticizes the Obama administration for "attempts to play the role of venture capitalist" on "politically prioritized investments" but then says he will prioritize technologies that "serve as the foundation for private-sector innovation and commercialization." He loses credit for ignoring the role of appropriate regulation in innovation.

4 **OBAMA** offers two policy proposals. First, he says he is "committed to doubling funding for key research agencies" (without specifying the agencies). Second, he says he has "set the goal of preparing 100,000 science and math teachers over the next decade." He loses credit for an incomplete answer.

CLIMATE CHANGE

The earth's climate is changing, and there is concern about the potentially adverse effects of these changes on life on the planet. What is your position on cap-and-trade, carbon taxes and other policies proposed to address global climate change? And what steps can we take to improve our ability to tackle challenges like climate change that cross national boundaries?

3 **OBAMA** rightly notes that "climate change is one of the biggest issues of this generation" and goes on to detail the modest ways his administration has attempted to address it: from improving vehicle fuel efficiency to reducing the federal government's greenhouse gas emissions. Yet Obama is vague about what role the U.S. should play in international efforts to curb global warming and omits any larger plan for reducing emissions domestically through new legislation or regulation. He gets credit for acknowledging the problem and for efforts that are already in place, but he loses credit for not specifying a path forward or stating his position on the policies outlined in the question.

1 **ROMNEY** reverses his previous statements and accepts the notion that human activity has caused changes in climate. Yet he inaccurately cites a "lack of scientific consensus" on the extent of human contributions and severity of the impacts and asserts his support for "continued debate." He correctly states that the problem is "global warming, not America warming." He calls for government investment in energy innovation research. But he does not address how his administration would work with other nations to reduce greenhouse gas pollution. He gets credit for clearly stating his position on the potential solutions in the question (he opposes them).

SCOTT OLSON *Getty Images*

TOM WILLIAMS Getty Images

RESEARCH AND THE FUTURE

Federally funded research has helped to produce America's major postwar economies and to ensure our national security, but today the U.K., Singapore, China and Korea are making competitive investments in research. Given that the next Congress will face spending constraints, what priority would you give to investment in research in your upcoming budgets?

(3) **OBAMA** highlights the research funding contained in the American Recovery and Reinvestment Act of 2009, aka the stimulus package. He touts the bill's $90 billion marked for clean energy projects as "the largest single investment in clean energy in American history." The Recovery Act was a one-time shot of money, however. He also includes vague statements supporting medical and defense research. Like Romney, Obama supports making the R&D tax credit permanent.

(2) **ROMNEY** writes that he is a "strong supporter of federally funded research," but he criticizes the $90 billion in clean energy funds in the stimulus package, saying that the same amount "could have funded the nation's energy research programs at the level recommended in a recent Harvard University study for nearly 20 years." Yet the report in question, "Transforming U.S. Energy Innovation," recommends spending billions in clean energy research (among other areas), and $90 billion would last nine years, not 20. Romney does not indicate what his research priorities would be.

PANDEMICS AND BIOSECURITY

Recent experiments show how avian flu may become transmissible among mammals. In an era of constant and rapid international travel, what steps should the U.S. take to protect our population from emerging diseases, global pandemics or deliberate biological attacks?

(4) **ROMNEY** commends the progress that researchers have made in "learning so much more about infectious diseases, how they work and how they spread." He asserts that "we must continue to invest in the best public health monitoring systems that can be built" and that he "will also encourage advancements in research and manufacturing to increase scientific understanding of new pathogens and improve response time when they emerge." He criticizes the Food and Drug Administration for "stifling medical innovation" but does not explain how he will ensure safety and efficacy if he lessens the FDA's influence.

(3) **OBAMA** correctly acknowledges the possibility of dangerous diseases entering the country and promises to "continue to work to strengthen our systems of public health." He notes that his administration is "working with the private sector to assess potential vulnerabilities." He does not, however, provide details about how to meet a pandemic or biological attack.

EDUCATION

Increasingly, the global economy is driven by science, technology, engineering and math. But a recent comparison of 15-year-olds in 65 countries found that average science scores among U.S. students ranked 23rd, whereas average U.S. math scores ranked 31st. In your view, why have American students fallen behind over the past three decades, and what role should the federal government play to better prepare students of all ages for the science- and technology-driven global economy?

(4) **OBAMA** has made improving math and science education a priority of his administration, and his answer highlights some of his goals, such as training 100,000 new science and math teachers over the next decade using mainly philanthropic and private funding. He does not mention his controversial Race to the Top program, which has used grants to encourage states to adopt tougher math standards and rigorous methods for evaluating teachers.

(3) **ROMNEY** fails to offer specific proposals for science and math education, choosing instead to talk about school reform in general. From his answer, it is unclear if he supports common state standards in math and science, which many think will improve student achievement. Although "recruiting and rewarding great teachers" is important, he does not explain how he will do it.

ENERGY

Many policy makers and scientists say energy security and sustainability are major problems facing the U.S. this century. What policies would you support to meet the demand for energy while ensuring an economically and environmentally sustainable future?

(2) **OBAMA** highlights the achievements of his first term in supporting an "all-of-the-above" approach to energy, from stimulus funding for wind farms and solar panels to the "safe, responsible development" of fracking for natural gas. He fails, however, to outline what future policies he might put in place to ensure responsible oil and gas development and reiterates his support for an alternative fuel—ethanol from corn—that has had serious impacts on food prices and the environment. He even invokes the shibboleth of "clean coal," development of which, in any event, has been stalled by the influx of cheap natural gas.

(1) **ROMNEY** confirms a commitment to what may well be a bipartisan pipe dream: "energy independence." After all, oil is sold in a global marketplace, and unless the U.S. were to withdraw from global oil markets, it is nearly impossible to imagine a scenario in which the country did not import oil. His recommendation would open up new areas to oil development, such as off the East Coast and in Florida. Romney gets credit for directness and completeness.

FOOD

Thanks to science and technology, the U.S. has the world's most productive and diverse agricultural sector. Yet many Americans are increasingly concerned about the health and safety of our food. The use of hormones, antibiotics and pesticides, as well as animal diseases and even terrorism, poses risks. What steps would you take to ensure the health, safety and productivity of America's food supply?

3 **OBAMA** outlines the steps his administration has already taken to ensure the integrity of the food supply, from much needed reform of the nation's food safety laws to cutting down on the use of pesticides and antibiotics by expanding organic operations. Unfortunately, antibiotic use is still widespread in meat production in the U.S. And he does not lay out an alternative vision for critical legislation governing food—such as the periodically renewed "farm bill."

2 **ROMNEY** lauds the American agricultural system, from "farmers and ranchers" to "grocers and restaurants." He promises that a "collaborative instead of combative relationship between regulators and businesses" will work to keep food safe. Yet he offers no evidence to support this assertion. Nor does he address the issues of hormones, antibiotics or pesticides.

FRESHWATER

Less than 1 percent of the world's water is liquid freshwater, and scientific studies suggest that a majority of U.S. and global freshwater is now at risk because of increasing consumption, evaporation and pollution. What steps, if any, should the federal government take to secure clean, abundant freshwater for all Americans?

3 **OBAMA** refers to his clean water policies and rural infrastructure investments, which are indeed positive actions. He does not refer to specific initiatives to improve the water efficiency of farming—by far the largest user of underground aquifers. The mountaintop-removal method of coal mining is also ruining streams at alarming rates, but he does not mention this fact. He also loses points for not acknowledging the magnitude of the problem.

1 **ROMNEY** does not offer a single, specific step to improve water quality or supply. His reply is evasive and implies that regulations are the only problem, stating that "communities and businesses must contend with excessively costly and inflexible approaches that impose unnecessary economic constraints and trigger inevitable litigation."

THE INTERNET

The Internet is central to both our economy and our society. What part, if any, should the federal government play in managing the Internet to ensure its robust social, scientific and economic role?

3 **OBAMA'S** anodyne answer hits all the right notes but falls short on specifics. He correctly worries about possible unintended effects of efforts to combat Internet piracy but gives no hints as to how he might satisfy both the concerns of Hollywood copyright holders and Silicon Valley entrepreneurs. Similarly, he gives a nod to the tension between cybersecurity and civil liberties but offers no specific policies to remedy the situation.

0 **ROMNEY** celebrates the Internet as a platform "open to all ideas and lawful commerce," then proceeds to harshly criticize the very principle that has kept the Internet so dynamic and open: network neutrality, the idea that all data should be treated equally. He falsely asserts that network neutrality would pick "winners and losers in the marketplace and [determine] how consumers will receive access to tomorrow's new applications and services." In fact, the opposite is true: network neutrality is essential for ensuring that fledgling Internet companies live and die on their merits and that cable companies and other large network service providers will not be able to block Internet-based services of which they disapprove.

OCEAN HEALTH

Scientists estimate that 75 percent of the world's fisheries are in serious decline, habitats such as coral reefs are threatened, and large areas of oceans and coastlines are polluted. What role should the federal government play, domestically and through foreign policy, to protect the environmental health and economic vitality of the oceans?

3 **OBAMA** addresses habitats and coastlines well but takes a pass on fisheries, other than to say his administration will monitor fishing stocks. He shows some scientific savvy by including the Great Lakes in "ocean health" because they are a similarly huge resource and may be in great trouble. U.S. ocean regulations are a mess, with dozens of agencies having varying jurisdictions, so streamlining is necessary. The National Ocean Policy is Obama's attempt to do that, and it has critics, but it is a start. Neither Obama nor Romney delves into the international aspect of ocean issues.

2 **ROMNEY** begins his answer by seeming to acknowledge that government has a role to play in protecting fisheries, despite his general stance against regulation. Yet he ended up saying the government should perform research and make it available—which it already does—and that his administration would listen to fishers' take on the issue. For Romney, protecting fisheries is a way to bolster the fishing industry, which is legitimate and much needed. His answer, however, gives no hint that he is aware of the large amount of data on ocean health that already exists or of its conclusions. He loses credit for that and for not addressing habitats and coastlines.

SCIENCE IN PUBLIC POLICY

We live in an era when science and technology affect every aspect of life and society and so must be included in well-informed public policy decisions. How will you ensure that policy and regulatory decisions are fully informed by the best available scientific and technical information and that the public is able to evaluate the basis of these policy decisions?

3 **OBAMA,** without mentioning former president George W. Bush by name, implies that the current administration uses scientific information differently than the previous one, which tried to suppress data that contradicted conservative policies on climate change and workplace safety. In general, the Obama administration has not tried to distort scientific data and analyses to serve its own policy ends. Neither has it escaped unscathed, however. One high-level Obama appointee, who resigned in the summer, was criticized for being overzealous in weakening new rules—often after appeals from corporate interests.

2 **ROMNEY** accuses Obama of trying to manipulate technical data, the same charge leveled by Democrats against Bush but one harder to justify with Obama. The challenger suggests that a proposed rule to reduce mercury pollution was a ploy to kill the coal industry by boosting costs. In reality, coal companies are under duress because of low-cost natural gas, not the prospect of new regulation.

SPACE

The U.S. is currently in a major discussion over our national goals in space. What should America's space exploration and utilization goals be in the 21st century, and what steps should the government take to help achieve them?

3 **ROMNEY** correctly charges that the "current purpose and goals of the American space program are difficult to determine," but he does not propose an alternative vision. Instead he promises to set priorities after consulting with stakeholders. He vows to engage international allies in space missions and hails the recent successes of private spaceflight companies. Romney says directly that NASA does not need more money to be successful, which gives him an edge in feasibility. Yet he received a middling score on completeness for outlining only guiding principles rather than specific plans.

3 **OBAMA** reiterates his stated goal of sending astronauts "to an asteroid by 2025 and to Mars in the 2030s," and he promises to uphold U.S. leadership in robotic space exploration. He makes no mention of preserving or increasing NASA's funding to accomplish those feats, however. Indeed, his administration's most recent budget request proposed deep cuts to robotic exploration. Obama scores high on directness but loses on feasibility for failing to deal with critical funding issues.

CRITICAL NATURAL RESOURCES

Supply shortages of natural resources affect economic growth, quality of life and national security. For example, China currently produces 97 percent of rare-earth elements needed for advanced electronics. What steps should the federal government take to ensure the quality and availability of critical natural resources?

3 **OBAMA** indicates that the best way to reduce dependence on China's rare-earth elements is to recycle products (to recapture the minerals) and to design future products that do not rely so heavily on them. Those strategies can help, but Obama is silent on domestic supply, which centers on the Mountain Pass mine in California. Unocal, now part of Chevron, ran the mine for decades but closed it in 2002 when faced with lowball prices from expanding Chinese suppliers and with stiffer state regulations on its radioactive wastewater. A new owner, Molycorp, reopened the mine in 2012.

3 **ROMNEY** hits this question head-on, stating that the U.S. could supply its own rare-earth elements if it "modernized" environmental regulations, which he blames for shutting down the Mountain Pass mine (although he does not name it). He also advocates letting states "manage the development of energy resources within their borders, including on federal lands." Romney says that plan would benefit all forms of energy, but its effects would fall mainly on oil, natural gas and coal.

VACCINATION AND PUBLIC HEALTH

Vaccination campaigns against preventable diseases such as measles, polio and whooping cough depend on widespread participation to be effective. In some communities, however, vaccination rates have fallen off sharply. What actions would you support to enforce vaccinations in the interest of public health, and in what circumstances should exemptions be allowed?

4 **ROMNEY** correctly notes that the "vaccines only work to prevent outbreaks when a sufficient number of people are protected from the diseases" but offers no solutions to increase vaccination rates. He focuses on business aspects of making and researching vaccines and scores higher on feasibility but loses credit for not answering the question completely.

4 **OBAMA** uses the question as a springboard to talk about the Affordable Care Act (ACA), which was enacted into law in 2010. He accurately notes that the ACA is expanding access to preventive health care services, including vaccines. Yet he ignores a major reason why vaccine rates are falling in some communities—the erroneous belief that vaccines might cause autism.

When facts become opinions, the collective policymaking process of democracy breaks down. Gone is the common denominator—knowledge—that can bring opposing sides together.

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Continued from page 65

Akin, who is running in Missouri against Claire McCaskill, said that from what he understood from doctors, pregnancy from rape is extremely rare because "if it's a legitimate rape, the female body has ways to try to shut that whole thing down." Akin sits on the House Committee on Science, Space, and Technology, which is responsible for much of the U.S. federal science enterprise, so he should be aware of what science actually says about key policy issues. In fact, studies suggest that women are perhaps twice as likely to become pregnant from rape, and, in any event, there is no biological mechanism to stop pregnancy in the case of rape. Akin's views are by no means unusual among abortion foes, who often seek to minimize what science says to politically justify a no-exception antiabortion stance, which has since become part of the 2012 national GOP platform.

A look at down-ticket races suggests that things may get worse. The large crop of antiscience state legislators elected in 2010 are likely to bring their views into mainstream politics as they eventually run for Congress. In North Carolina this year the state legislature considered House Bill No. 819, which prohibited using estimates of future sea-level rise made by most scientists when planning to protect low-lying areas. (Increasing sea level is a predicted consequence of global warming.) The proposed law would have permitted planning only for a politically correct rise of eight inches instead of the three to four feet that scientists predict for the area by 2100.

Virginia Republicans took similar action in June, banning the use of the term "sea-level rise" from a government-commissioned study and instead requiring use of the phrase "recurrent flooding" because "sea-level rise" is considered "a left-wing term," according to one of the legislators.

THE EVOLUTION OF AMERICAN SCIENCE DENIALISM

THE AMERICAN ANTISCIENCE MOVEMENT did not travel from the fringe to the center of society overnight. Its roots can be traced back a century to three-time Democratic candidate for president William Jennings Bryan, who ran fundamentalist campaigns against the theory of evolution, which he argued was causing moral decay in the nation's youth by undermining the authority of the Bible.

Bryan lost to proscience Republicans William McKinley and William Howard Taft, but he continued to campaign throughout the South, working to banish the scientific theory from American classrooms. Eventually Tennessee passed a law prohibiting the teaching of "any theory that denies the Story of the Divine Creation of man as taught in the Bible, and to teach instead that man has descended from a lower order of animals." The coverage of the resulting Scopes "monkey trial" in 1925 turned the American public against religious fundamentalism for a generation, and the persistent campaigns against evolution drove most scientists into the Republican Party.

When World War II broke out, science gained new luster. President Franklin D. Roosevelt turned to science as an intellectual weapon to help win the war. FDR asked Vannevar Bush, who led what is now known as the Carnegie Institution for Science, to marshal the U.S. science enterprise. Bush's efforts succeeded, leading to the development of radar, artificial rubber, the mass production of penicillin and the atomic bomb. After the war, he convinced President Harry S. Truman that continued federal investment in science could make the U.S. into a world leader.

The investment paid off, but the steady flow of federal funding had an unanticipated side effect. Scientists no longer needed to reach out to the public or participate in the civic conversation to raise money for research. They consequently began to withdraw from the national public dialogue to focus more intently on their work and private lives. University tenure systems grew up that provided strong disincentives to public outreach, and scientists came to view civics and political involvement as a professional liability.

As the voice of science fell silent, the voice of religious fundamentalism was resurging. Moral disquietude over the atomic bomb caused many to predict the world would soon end, and a new wave of fundamentalist evangelists emerged. "All across Europe, people know that time is running out," a charismatic young preacher named Billy Graham said in 1949. "Now that Russia has the atomic bomb, the world is in an armament race driving us to destruction."

Increasing control over the reproductive process widened the split in the following years. Religious conservatives felt that humans should not interfere in God's plan, denouncing the growing popularity of the birth-control pill in the 1960s and debating in the 1970s whether "test-tube babies," produced by in vitro fertilization, would have souls. They redefined pregnancy to begin at fertilization, rather than implantation in the uterine wall, and argued that abortion was murder.

Science's black eye grew with the broader public as well. In the 1950s children played in the fog of DDT as trucks sprayed neighborhoods, but with the 1962 publication of Rachel Carson's *Silent Spring,* we learned it was toxic. This pattern repeated over and over again as unforeseen health and environmental consequences of quickly commercialized science came to light. Similar scandals erupted over the effects of scores of industrial applications, ranging from sulfur dioxide and acid rain, to certain aerosols and the hole in the ozone layer, to leaded gas and cognitive impairment, to the granddaddy of them all, fossil fuels and global climate change.

Industrial mishaps led to new health and environmental regulatory science. The growing restrictions drove the older industries in the chemical, petroleum and pharmaceutical fields to protect their business interests by opposing new regulations. Proponents of this view found themselves in a natural alliance with the burgeoning religious fundamentalists who opposed the teaching of evolution. Industrial money and religious foot soldiers soon formed a new basis for the Republican Party: "In this present crisis, government is not the solution to our problem," President Ronald Reagan argued in his 1981 inaugural address. "Government is the problem." This antiregulatory-antiscience alliance largely defines the political parties today and helps to explain why, according to a 2009 survey, nine out of 10 scientists who identified with a major political party said they were Democrats.

This marriage of industrial money with fundamentalist values gave fundamentalism renewed power in the public debate, and efforts to oppose the teaching of evolution in public schools have returned in several states. Tennessee, South Dakota and Louisiana have all recently passed legislation that encourages unwarranted criticisms of evolution to be taught in the states' public schools. Evangelical state legislators and school board members mounted similar efforts this year in Oklahoma, Missouri, Kansas, Texas and Alabama, and the Texas Republican Party platform opposes "the teaching of … critical thinking skills and similar programs that … have the purpose of challenging the student's fixed beliefs and undermining parental authority."

AN ANTISCIENCE PHILOSOPHY

IF BOTH DEMOCRATS AND REPUBLICANS have worn the antiscience mantle, why not just wait until the pendulum swings again and denialism loses its political potency? The case for action rests on the realization that for the first time since the beginning of the Enlightenment era in the mid-17th century, the very idea of science as a way to establish a common book of knowledge about the world is being broadly called into question by heavily financed public relations campaigns.

Ironically, the intellectual tools currently being used by the political right to such harmful effect originated on the academic left. In the 1960s and 1970s a philosophical movement called postmodernism developed among humanities professors displeased at being deposed by science, which they regarded as right-leaning. Postmodernism adopted ideas from cultural anthropology and relativity theory to argue that truth is relative and subject to the assumptions and prejudices of the observer. Science is just one of many ways of knowing, they argued, neither more nor less valid than others, like those of Aborigines, Native Americans or women. Furthermore, they defined science as the way of knowing among Western white men and a tool of cultural oppression. This argument resonated with many feminists and civil-rights activists and became widely adopted, leading to the "political correctness" justifiably hated by Rush Limbaugh and the "mental masturbation" lampooned by Woody Allen.

Acceptance of this relativistic worldview undermines democracy and leads not to tolerance but to authoritarianism. John Locke, one of Jefferson's "trinity of three greatest men," showed why almost three centuries ago. Locke watched the arguing factions of Protestantism, each claiming to be the one true religion, and asked: How do we know something to be true? What is the basis of knowledge? In 1689 he defined what knowledge is and how it is grounded in observations of the physical world in *An Essay Concerning Human Understanding*. Any claim that fails this test is "but faith, or opinion, but not knowledge." It was this idea—that the world is knowable and that objective, empirical knowledge is the most equitable basis for public policy—that stood as Jefferson's foundational argument for democracy.

By falsely equating knowledge with opinion, postmodernists and antiscience conservatives alike collapse our thinking back to a pre-Enlightenment era, leaving no common basis for public policy. Public discourse is reduced to endless warring opinions, none seen as more valid than another. Policy is determined by the loudest voices, reducing us to a world in which might makes right—the classic definition of authoritarianism.

Postmodernism infiltrated a generation of American education programs, as Allan Bloom first pointed out in *The Closing of the American Mind*. It also infected journalism, where the phrase "there is no such thing as objectivity" is often repeated like a mantra.

Reporters who agree with this statement will not dig to get to the truth and will tend to simply present "both sides" of contentious issues, especially if they cannot judge the validity of scientific evidence. This kind of false balance becomes a problem when one side is based on knowledge and the other is merely an opinion, as often occurs when policy problems intersect with science. If the press corps does not strive to report objective reality, for which scientific evidence is our only reliable guide, the ship of democracy is set adrift from its moorings in the well-informed voter and becomes vulnerable once again to the tyranny that Jefferson feared.

AN EXISTENTIAL CRISIS

"FACTS," JOHN ADAMS ARGUED, "are stubborn things; and whatever may be our wishes, our inclinations, or the dictates of our passion, they cannot alter the state of facts and evidence." When facts become opinions, the collective policymaking process of democracy begins to break down. Gone is the common denominator—knowledge—that can bring opposing sides together. Government becomes reactive, expensive and late at solving problems, and the national dialogue becomes mired in warring opinions.

In an age when science influences every aspect of life—from the most private intimacies of sex and reproduction to the most public collective challenges of climate change and the economy—and in a time when democracy has become the dominant form of government on the planet, it is important that the voters push elected officials and candidates of all parties to explicitly state their views on the major science questions facing the nation. By elevating these issues in the public dialogue, U.S. citizens gain a fighting chance of learning whether those who would lead them have the education, wisdom and courage necessary to govern in a science-driven century and to preserve democracy for the next generation. SA

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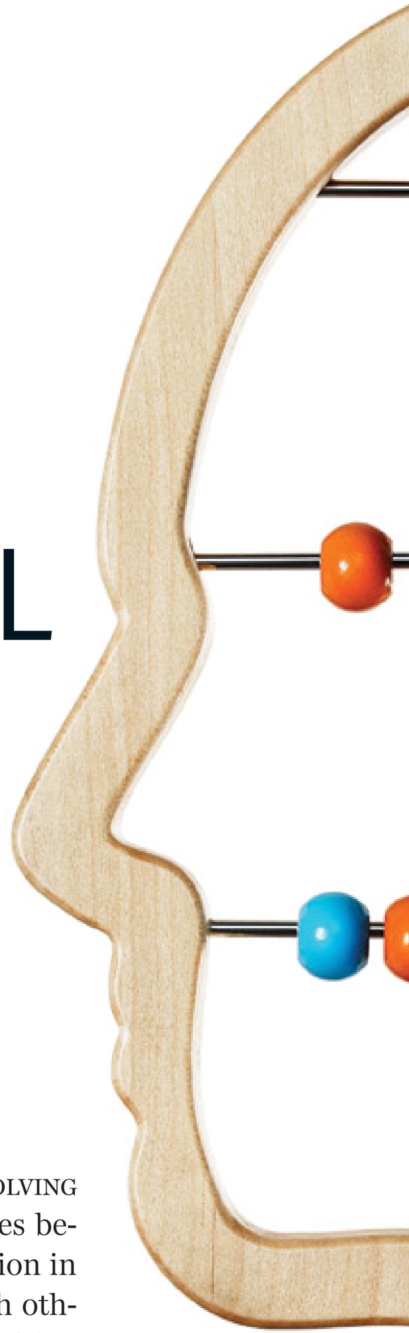
SCIENTIFIC AMERICAN ONLINE
To learn more about the intersection of science and key election issues, as well as to read the answers from the presidential candidates and key congressional leaders, visit **ScientificAmerican.com/nov2012/science-debate**

Simon Baron-Cohen is professor of developmental psychopathology at the University of Cambridge and director of the Autism Research Center. He is author of *The Essential Difference* (Basic Books, 2004), among other books.

BIOLOGY

AUTISM AND THE TECHNICAL MIND



Children of scientists and engineers may inherit genes that not only confer intellectual talents but also predispose them to autism

By Simon Baron-Cohen

IN 1997 MY COLLEAGUE SALLY WHEELWRIGHT AND I CONDUCTED A STUDY INVOLVING nearly 2,000 families in the U.K. We included about half these families because they had at least one child with autism, a developmental condition in which individuals have difficulty communicating and interacting with others and display obsessive behaviors. The other families had children with a diagnosis of Tourette's syndrome, Down syndrome or language delays but not autism. We asked parents in each family a simple question: What was their job? Many mothers had not worked outside the home, so we could not use their data, but the results from fathers were intriguing: 12.5 percent of fathers of

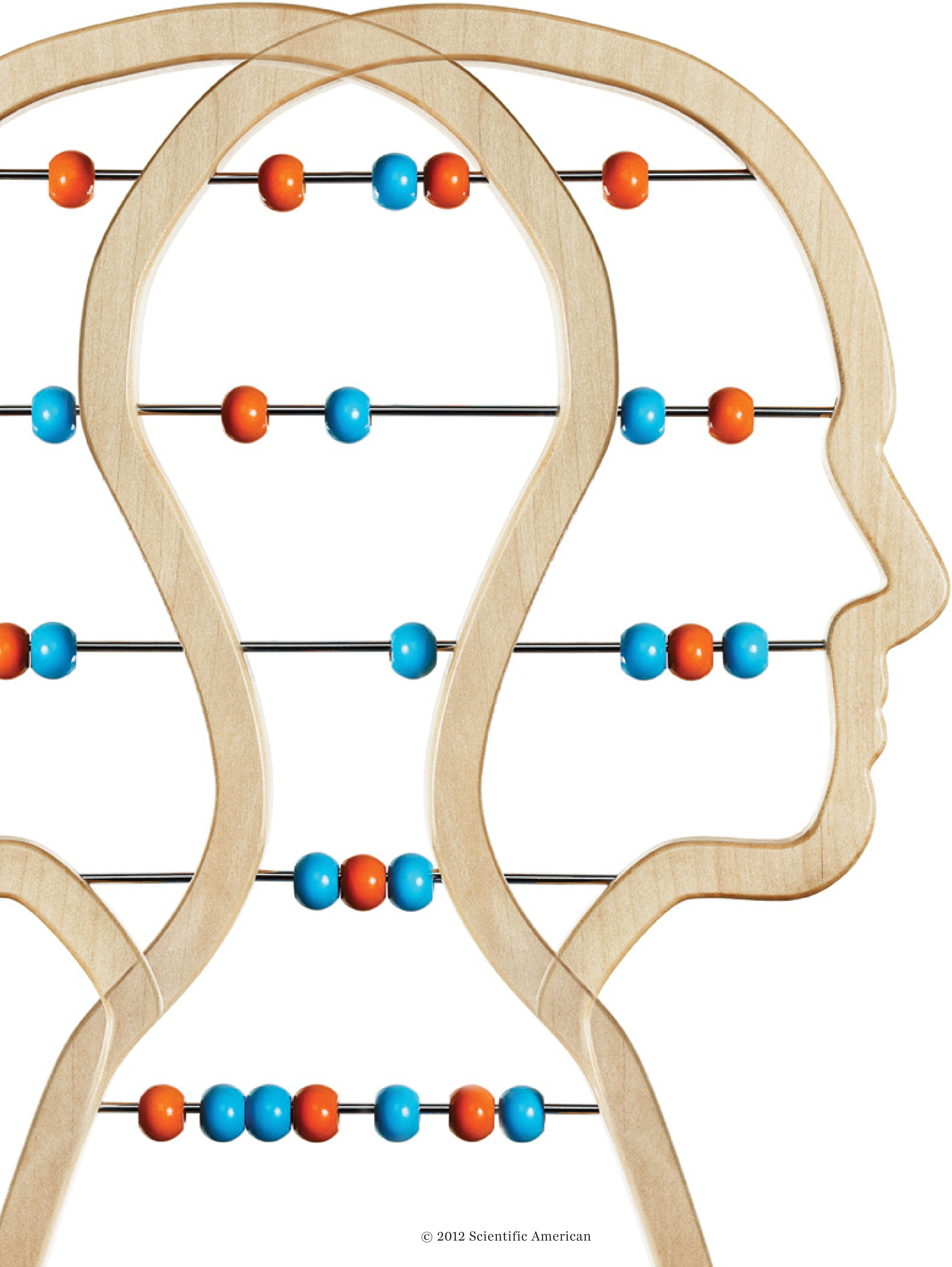
IN BRIEF

Silicon Valley and other tech-savvy communities report exceptionally high rates of autism. These trends might reflect a link between genes that contribute to autism and genes behind technical aptitude.

When two technical-minded individuals pair up, their children may inherit genes for useful cognitive skills, as well as genes involved in the development of autism.

Furthermore, high levels of testosterone in the womb may play a role in the development of both technical and autistic minds.

Photograph by Dan Saelinger



children with autism were engineers, compared with only 5 percent of fathers of children without autism.

Likewise, 21.2 percent of grandfathers of children with autism had been engineers, compared with only 2.5 percent of grandfathers of children without autism. The pattern appeared on both sides of the family. Women who had a child with autism were more likely to have a father who had been an engineer—and they were more likely to have married someone whose father had been an engineer.

Coincidence? I think not.

A possible explanation involves a phenomenon known as assortative mating, which usually means "like pairs with like." I first encountered the concept in an undergraduate statistics tutorial at the University of Oxford in 1978, when my tutor told me (perhaps to make statistics a little more lively) that whom you have sex with is not random. When I asked her to elaborate, she gave me the example of height: tall people tend to mate with tall people, and short people tend to mate with short people. Height is not the only characteristic that consciously and subconsciously influences partner selection—age is another example, as are personality types. Now, more than 30 years later, my colleagues and I are testing whether assortative mating explains why autism persists in the general population. When people with technical minds—such as engineers, scientists, computer programmers and mathematicians—marry other technical-minded individuals, or their sons and daughters do, do they pass down linked groups of genes that not only endow their progeny with useful cognitive talents but also increase their children's chances of developing autism?

SYSTEM CHECK

I BEGAN STUDYING AUTISM in the 1980s. By then, the psychogenic theory of autism—which argued that emotionally disinterested mothers caused their children's autism—had been soundly refuted. Michael Rutter, now at King's College London, and others had begun to study autism in twins and had shown that autism was highly heritable. Genetics, not parenting, was at work.

Today researchers know that an identical twin of someone with autism is around 70 times more likely to develop autism, too, compared with an unrelated individual. Although researchers have uncovered associations between specific genes and autism, no one has identified a group of genes that reliably predicts who will develop the condition. The genetics of autism are far more complex than that. What I have been interested in understanding, however, is how genes for autism survive in the first place. After all, autism limits one's abilities to read others' emotions and to form relationships, which in turn may reduce one's chances of having children and passing on one's genes.

One possibility is that the genes responsible for autism persist, generation after generation, because they are co-inherited with genes underlying certain cognitive talents common to both people with autism and technical-minded people whom some might call geeks. In essence, some geeks may be carriers of genes for autism: in their own life, they do not demonstrate any signs of severe autism, but when they pair up and have kids, their children may get a double dose of autism genes and traits. In this way, assortative mating between technical-minded people might spread autism genes.

Because "geek" is not the most scientific term, and for some may be pejorative, I needed to formulate a more precise definition of the cognitive talents shared by technical-minded people and people with autism. In the early 2000s Wheelwright and I surveyed nearly 100 families with at least one child with autism and asked another basic question: What was their child's obsession? We received a diverse array of answers that included memorizing train timetables, learning the names of every member of a category (for instance, dinosaurs, cars, mushrooms), putting electrical switches around the house into particular positions, and running the water in the sink and rushing outside to see it flowing out of the drainpipe.

On the surface, these very different behaviors seem to share little, but they are all examples of systemizing. I define systemizing as the drive to analyze or construct a system—a mechanical system (such as a car or computer), a natural system (nutrition) or an abstract system (mathematics). Systemizing is not restricted to technology, engineering and math. Some systems are even social, such as a business, and some involve artistic pursuits, such as classical dance or piano. All systems follow rules. When you systemize, you identify the rules that govern the system so you can predict how that system works. This fundamental drive to systemize might explain why people with autism love repetition and resist unexpected changes.

Collaborating once again with Wheelwright, who is now at the University of Southampton in England, I put the link between systemizing and autism to the test. We found that children with Asperger's syndrome—a form of autism with no language or intelligence impairments—outperformed older, typically developing children on a test of understanding mechanics. We also found that on average, adults and children with Asperger's scored higher on self-report and parent-report measures of systemizing. Finally, we found that people with Asperger's scored higher on a test of attention to detail. Attention to detail is a prerequisite for good systemizing. It makes a world of difference when trying to understand a system if you spot the small details or if you mistake one tiny variable in the system. (Imagine getting one digit wrong in a math calculation.) When we gave the test of attention to detail to parents, both the mothers and fathers of children with autism were also faster and more accurate than those of typically developing children.

Engineers aren't the only technical-minded people who might harbor autism genes. In 1998 Wheelwright and I found that math students at the University of Cambridge were nine times more likely than humanities students to report having a formal diagnosis of autism, including Asperger's, which will be folded into the broader "autism spectrum disorder" in the newest edition of psychiatry's guidebook, the *DSM-5*. Whereas only 0.2 percent of students in the humanities had autism, a figure not so different from the rate of autism reported in the wider population at the time, 1.8 percent of the math students had it. We also found that the siblings of mathematicians were five times more likely to have autism, compared with the siblings of those in the humanities.

In another test of the link between autism and math, Wheelwright and I developed a metric for measuring traits associated with autism in the general population, called the Autism Spectrum Quotient (AQ). It has 50 items, each representing one such trait. No one scores zero on the test. On average, typically developing men score 17 out of 50, and typically developing women score 15 out of 50. People with autism usually score above 32. We gave the AQ to winners of the British Mathematical Olympiad.

They averaged 21 out of 50. This pattern suggested that—regardless of official diagnoses—mathematical talent was also linked to a higher number of traits associated with autism.

THE SILICON VALLEY PHENOMENON

ONE WAY TO TEST the assortative mating theory is to compare couples in which both individuals are strong systemizers with couples who include only one strong systemizer—or none. Two-systemizer couples may be more likely to have a child with autism. My colleagues and I created a Web site where parents can report what they studied in college, their occupations, and whether or not their children have autism (www.cambridgepsychology.com/graduateparents).

Meanwhile we are exploring the theory from other angles. If genes for technical aptitude are linked to genes for autism, then autism should be more common in places around the world where many systemizers live, work and marry—places such as Silicon Valley in California, which some people claim has autism rates 10 times higher than the average for the general population.

In Bangalore, the Silicon Valley of India, local clinicians have made similar observations. Alumni of the Massachusetts Institute of Technology have also reported rates of autism 10 times higher than average among their children. Unfortunately, no one has yet conducted detailed and systematic studies in Silicon Valley, Bangalore or M.I.T., so these accounts remain anecdotal.

My colleagues and I, however, have investigated the rates of autism in Eindhoven, the Silicon Valley of the Netherlands. Royal Philips Electronics has been a major employer in Eindhoven since 1891, and IBM has a branch in the city. Indeed, some 30 percent of jobs in Eindhoven are in the IT sector. Eindhoven is also home to Eindhoven University of Technology and High Tech Campus Eindhoven, the Dutch equivalent of M.I.T. We compared rates of autism in Eindhoven with rates of autism in two similarly sized cities in the Netherlands: Utrecht and Haarlem.

In 2010 we asked every school in all three cities to count how many children among their pupils had a formal diagnosis of autism. A total of 369 schools took part, providing information on about 62,505 children. We found that the rate of autism in Eindhoven was almost three times higher (229 per 10,000) than in Haarlem (84 per 10,000) or Utrecht (57 per 10,000).

MALE MINDS

IN PARALLEL WITH TESTING the link between autism and systemizing, we have been examining why autism appears to be so much more common among boys than among girls. In classic autism, the sex ratio is about four boys to every girl. In Asperger's, the sex ratio may be as high as nine boys for every girl.

Likewise, strong systemizing is much more common in men than in women. In childhood, boys on average show a stronger interest in mechanical systems (such as toy vehicles) and constructional systems (such as Lego). In adulthood, men are overrepresented in STEM subjects (*s*cience, *t*echnology, *e*ngineering and *m*ath) but not in people-centered sciences such as clinical psychology or medicine. We have been investigating whether high levels of the hormone testosterone in the fetus, long known to play a role in "masculinizing" the developing brain in animals, correlate with strong systemizing and more traits associated with autism. A human male fetus produces at least twice as much testosterone as a female fetus does.

To test these ideas, my colleague Bonnie Auyeung of the Cambridge Autism Research Center and I studied 235 pregnant women undergoing amniocentesis—a procedure in which a long needle samples the amniotic fluid surrounding a fetus. We found that the more testosterone surrounding a fetus in the womb, the stronger the children's later interest in systems, the better their attention to detail and the higher their number of traits associated with autism. Researchers in Cambridge, England, and Denmark are now collaborating to test whether children who eventually develop autism were exposed to elevated levels of testosterone in the womb.

Genes that contribute to autism may overlap with genes for the uniquely human ability to understand how the world works in detail—to see beauty in patterns inherent in nature, music and math.

If fetal testosterone plays an important role in autism, women with autism should be especially masculinized in certain ways. Some evidence suggests that this is true. Girls with autism show "tomboyism" in their toy-choice preferences. On average, women with autism and their mothers also have an elevated rate of polycystic ovary syndrome, which is caused by excess testosterone and involves irregular menstrual cycles, delayed onset of puberty and hirsutism (excessive body hair).

Prenatal testosterone, if it is involved in autism, is not acting alone. It behaves epigenetically, changing gene expression, and interacts with other important molecules. Similarly, the link between autism and systemizing, if confirmed through further studies, is unlikely to account for the full complexity of autism genetics. And we should not draw the simplistic conclusion that all technical-minded people carry genes for autism.

Investigating why certain communities have higher rates of autism, and whether genes that contribute to the condition are linked to genes for technical aptitude, may help us understand why the human brain sometimes develops differently than usual. People with autism, whose minds differ from what we consider typical, frequently display both disability and exceptional aptitude. Genes that contribute to autism may overlap with genes for the uniquely human ability to understand how the world works in extraordinary detail—to see beauty in patterns inherent in nature, technology, music and math. SA

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SCIENTIFIC AMERICAN ONLINE
Participate in a live chat with Baron-Cohen about autism and the technical mind. For details, visit **ScientificAmerican.com/nov2012/baron-cohen**


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QUANTUM PHYSICS

A NEW ENLIGHTENMENT

Quantum theory once seemed like the last nail in the coffin of pure reason. Now it's looking like its savior

By George Musser

Illustrations by Oliver Munday

AN AMERICAN ELECTION SEASON

seems like a bad time to sing the praises of human rationality. Candidates make promises that will never be kept yet voters somehow accept; thoughtful arguments hold no sway, while sound bites carry the day. What a comedown from the Enlightenment ideals, the faith in rationality, that inspired the founding of the republic. And it is even worse than you might think. Some things you think should be possible to figure out rationally if only you exerted yourself aren't. If you actually succeeded in living a life of reason—never voting without weighing each candidate's record carefully, never buying an appliance without consulting *Consumer Reports,* never begging the question, never erecting straw men, never falling into any of the other traps that flesh is heir to—you still would find yourself doing things that made no sense, not because you had failed but because reason itself is a saw blade missing a few teeth.

Throughout the 20th century scientists and mathematicians have had to accept that some things will always remain beyond the grasp of reason. In the 1930s Kurt Gödel famously showed that even in the rational universe of mathematics, for every paradox that deep thinking slaps down, new ones pop up. Economists and political theorists found similar limitations to rational rules for organizing society, and historians of science punctured the belief that scientific disputes are resolved purely by facts. The ultimate limits on reason come from quantum physics, which says that some things just happen and you can never know why.

Yet events have taken a strange turn in the past decade. The very theory of quantum physics that seemed to box in human knowledge also proves to liberate us. It expands our knowledge not just of the physical world but also of ourselves. By enriching the rules of rational thought, it gets us out of dead ends where reason leads us. Taken in the broader framework quantum physics provides, human behavior may not be as irrational as the evening news makes it seem.

THE WEIGHT OF REASON

FEW LIVED AND BREATHED the Enlightenment dream more than the Marquis de Condorcet, one of the leading mathematicians of the late 18th century. Emboldened by the success of Newtonian physics, a few simple rules that explained the fall of apples and the orbits of planets, he sought to create a science of society to match. Reason, he thought, could make the world a better place. He and other Enlightenment thinkers campaigned for a progressive political agenda: the abolition of slavery, equal rights for women, universal public education. A friend of Thomas

IN BRIEF

Quantum physicists have discovered that quantum mechanics enlarges our capacity to reason in unexpected ways. The notorious Prisoner's Dilemma, in which the rational choice is the wrong choice, can be eliminated by quantum entanglement. A more recent (and still unproved) claim is that a quantum system of voting could avoid the inconsistencies of ordinary voting.

Quantum mechanics may be a better model for human behavior than classical logic, which fails to predict the human impulse to cooperate and act altruistically. Instead of trying to force our thinking into a rational framework, we are better off expanding the framework.

Jefferson, Benjamin Franklin and Thomas Paine, Condorcet became an early leader of the French Revolution. "The moment will come when the sun will shine only on a planet of free men, knowing only reason as their master … learning how to recognize and smother beneath the weight of reason the first signs of superstition and tyranny, should they ever dare to reappear," he wrote in 1794.

Then came the fall. The revolution took its dark turn. Condorcet was arrested, died in prison the next day and was buried in a communal grave that was later lost. The Enlightenment gave way to Romanticism. For many leading thinkers, the excesses of the revolution discredited the entire progressive agenda.

As if to heighten the tragedy, Condorcet had come to question the Enlightenment idea of the will of the people. He showed that democratic voting systems lead to paradoxes: people's choices can add up in mutually contradictory and unresolvable ways. Mathematician and political essayist Piergiorgio Odifreddi of the University of Turin in Italy gives an example: In the 1976 U.S. presidential election, Gerald Ford secured the Republican nomination after a close race with Ronald Reagan, and Jimmy Carter beat Ford in the general election, but polls suggested Reagan would have beaten Carter (as indeed he did in 1980). The electorate's preferences were intransitive: preferring Carter to Ford and Ford to Reagan did not mean preferring Carter to Reagan. Carter won only because the primaries came first. "Who was elected is determined only by the order in which you do the two elections, not by the electorate," Odifreddi says. In committees and legislatures, presiding officers can exploit this order dependence, or noncommutativity, to steer a vote their way.

QUANTUM PHYSICS PROVIDES A MODEL FOR HUMAN BEHAVIOR IN WHICH IRRATIONALITY MAKES TOTAL SENSE.

In 1950 Kenneth Arrow, then a graduate student at Columbia University, showed that there is only one sure way to avoid paradox: dictatorship. The order of the elections no longer matters when one voter has decisive power. This sobering discovery helped win Arrow the 1972 Nobel Prize in Economics. "It's an analogue of Gödel's theorem," Odifreddi says. "It proves there are limitations to the general idea we have of democracy." Gödel himself may have formulated a version of Arrow's theorem even earlier; similar ideas appear in an argument he gave for the existence of God.

If democracies usually avoid Condorcet's paradoxes, it is because voters lie on an ideological spectrum, giving their views some coherence and mutual consistency [see "The Fairest Vote of All," by Partha Dasgupta and Eric Maskin; Scientific American, March 2004]. Ironically, although Western culture valorizes independent, nonideological thinking, such thinking can actually cause a voting system to seize up. In politically unsettled times, Odifreddi says, the spectrum gets tangled, and democracy becomes not just somewhat but completely dysfunctional.

The same year that Arrow proved his theorem, mathematicians Merrill Flood and Melvin Dresher discovered another conflict between individual and collective decisions: the Prisoner's Dilemma. The police catch two thieves and offer each a reward for snitching on the other. If both stay mum, both get off scot-free; if both snitch, both get the book thrown at them. Given these incentives to snitch, both do—but then both lose [*see box on next two pages*]. This dilemma is a model for the limitations of laissez-faire economics. It punctures the neoclassical economic wisdom that individuals acting in their own rational self-interest collectively produce the best outcome.

A related letdown is the "liberal paradox" that economist Amartya Sen of Harvard University articulated in 1970. Much as Arrow cast doubt on democracy and Flood on market economics, Sen blew a hole in the notion of individual rights. The most basic right is that an individual should have veto power over decisions that affect only him or her. Sen's original example was censorship: the decision to read or not read a book affects only that person and therefore should fall under his or her control. Majority rule has always been in tension with individual rights: a majority can impose its will on a minority. What is stranger is that even *unanimous* rule violates rights—in other words, an individual's rights can be threatened by decisions the individual implicitly supports.

In a not so hypothetical variant on Sen's example, consider two voters, Blue and Red, passing judgment on a government welfare program. Blue prefers that both of them receive the benefits; failing that, he would like Red to get them, being the needier of the two. Red prefers that neither get the benefits; failing that, he should be the one to get them—to save Blue from the corrupting influences of public assistance. Because they are deadlocked, they have to settle for their second choices. Thus, the program is foisted on Red and denied to Blue, so neither controls decisions that affect only them. All these paradoxes suggest that some disputes in our society go on and on not because people are being inconsistent or unreasonable but because the mechanisms of rational decision making, intended to reconcile diverse points of view, can instead heighten conflict.

PARADOX LOST

In the 1950s and 1960s mathematicians explored various ways to escape the Prisoner's Dilemma. One method was the use of conditional strategies. Instead of choosing between staying mum or snitching, each suspect could tell the interrogators, say, "If my partner stays mum, then I will, too." With the right set of if-then statements, the individuals can avoid jail time. Crucially, neither will gain by switching strategies, so a rational calculation of self-interest leads them to cooperate [see "Escape from Paradox," by Anatol Rapoport; Scientific American, July 1967]. What is best for the individual is best for the group. Yet the scheme does have a fatal flaw: the partners have to agree to stick to conditional strategies and to not change their mind at the last minute and snitch. They need a foolproof way to keep each other in line.

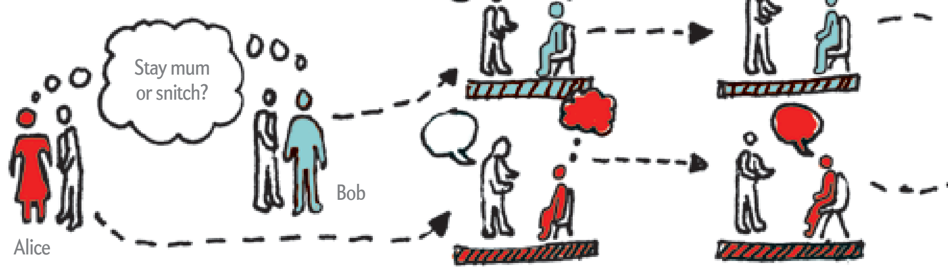
Quantum physics provides one. In 1998 physicists Jens Eisert and Martin Wilkens, both then at the University of Potsdam in Germany, and Maciej Lewenstein, then at the University of Hannover in Germany, suggested that a pair of entangled particles can serve as a binding contract [see "Schrödinger's Games," by Graham P. Collins; Scientific American, January 2000]. Through these particles, the partners can coordinate their decisions without knowing in advance what those decisions are—information they could have used to flout the contract. In 2001 Jiangfeng Du of the University of Science and Technology of China in Hefei

Freeing the Quantum Prisoners

It is conventional wisdom that people do not behave rationally. But what is "rational"? It simply means adherence to principles of classical logic. An expanded set of logical rules, first devised for quantum physics and now applied to psychology, can make sense of apparent irrationality. The famous Prisoner's Dilemma demonstrates how.

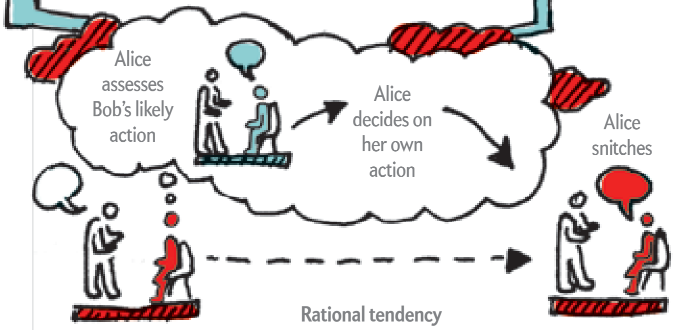
1 Setup of the Prisoner's Dilemma

Two suspected thieves, Alice and Bob, are arrested and interrogated. If both stay mum, both go free; if one snitches on the other, he or she goes free and gets a reward while the other goes to jail; if both snitch, both wind up behind bars.



2 Rational Thought Process

Alice assesses Bob's likely actions and realizes that no matter what he does, she is better off snitching. Bob reasons the same way. Result: both snitch, and both get punished. Rationally, they have no way to avoid this fate.

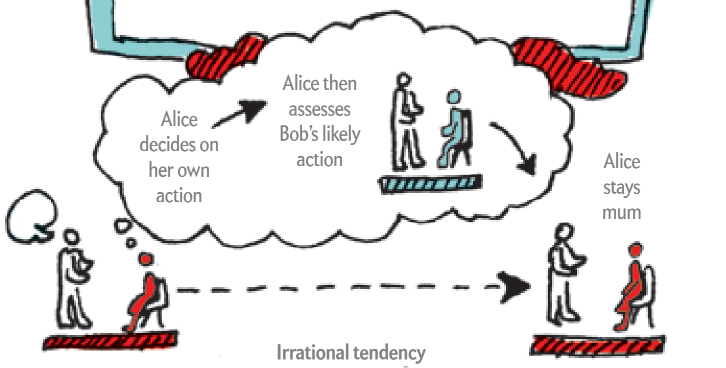


Rational tendency
Based on assessment, maximize self-interest

Assessment	Action
Bob will stay mum	Snitch
Bob will snitch	Snitch

3 Irrational Thought Process

Alice, prone to wishful thinking, imagines that if she stays mum, Bob will surely do the same. That is, she forms her assessment of Bob's actions based on her own. This unwarranted optimism creates the opening for a mutually beneficial outcome.



Irrational tendency
Based on intended action, alter assessment

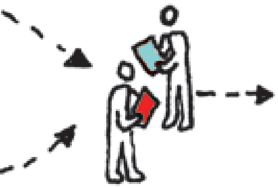
Intended action	Assessment
Stay mum	Bob will stay mum
Snitch	Bob will snitch

and his colleagues demonstrated the scheme in the laboratory. They entangled two hydrogen nuclei and beamed radio pulses at them to execute the stages of the game.

Italian mathematical physicist Gavriel Segre suggests that a similar trick could prevent voting deadlock without having to install a dictator. He says he became interested in the subject in the summer of 2008, when he read an interview of his compatriot Odifreddi in the newspaper *La Stampa*. Citing Arrow's theorem, Odifreddi asserted that representative democracy was obsolescent. "I didn't agree with this fact, and I began to think of a way to overcome the Arrow theorem," Segre says.

Segre argues that quantum physics enriches the possibilities of voting. Like Schrödinger's cat, a citizen can be of two minds, voting both yes and no—a so-called superposition. When aggregated, votes can either add up or negate one another. They can become entangled with one another, representing a kind of pact among citizens to vote in a coordinated way, like the binding contract in the quantum Prisoner's Dilemma. In this case, unlike the classical one Arrow considered, the will of the people can be perfectly consistent.

Unfortunately, Segre's proof is very abstract, and several experts on voting theory consulted for this article doubt whether it is correct, let alone whether it could be written into a 21st-century constitution. Yet physicist Artur Ekert of the University of Oxford and the Center for Quantum Technologies in Singapore says that Segre may be on to something. Because quantum physics is probabilistic, a quantum voting system may avoid inconsistencies without an absolute dictator—just a ruler whose say-so carries the day on average and can be overruled from time to time. "We will have a dictator but a much weaker one," Ekert says.

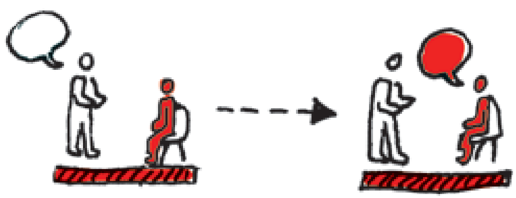


They are sentenced accordingly

ALICE'S ACTION	BOB'S ACTION: Stay mum	BOB'S ACTION: Snitch
Stay mum	Freedom Freedom	Maximum sentence Freedom and reward
Snitch	Freedom and reward Maximum sentence	Standard sentence Standard sentence

4 Where Quantum Reasoning Enters

Rational and irrational tendencies compete. The interrogator can affect the outcome by prejudicing each suspect about what the other will do. If the interrogator says nothing, logically the suspects should act as they did before. But when psychologists ask subjects to play the game, uncertainty tends to make many people less likely to snitch. A quantum model, in which probabilities of different outcomes combine in counterintuitive ways, explains why.



What interrogator says	What Alice does
"Bob will snitch"	Alice snitches 100% of the time
"Bob will stay mum"	Alice snitches 80% of the time
No information	**Classical:** Alice will snitch 90% of the time (average of 80% and 100%) **Quantum:** Alice snitches 60% of the time (the different reasons for snitching offset rather than add—as observed in a quantum model)

CRITIQUE OF PURE (CLASSICAL) REASON

QUANTUM PHYSICS does not erase the original paradoxes or provide a practical system for decision making unless public officials are willing to let people carry entangled particles into the voting booth or the police interrogation room. The real significance of these findings is that quantum physics provides a model for human behavior in which apparent irrationality makes total sense.

In real life, people cooperate much more often than they would if they were driven purely by a rational assessment of their self-interest. When psychologists ask volunteers to play the Prisoner's Dilemma, the players sometimes stay mum despite the strong incentive to snitch. If Alice believes Bob will snitch, she will definitely snitch. If she believes Bob will stay mum, she will probably still snitch but might stay mum. "Might" is typically just 20 percent of the time, but it shines a glimmer of hope into a mean-spirited game.

What is downright weird, though, is that if she is not sure what Bob will do, Alice becomes *more* likely to stay mum. No purely rational creature would do that. According to classical logic, if she thinks there is a 50–50 chance of Bob staying mum, she should take the average of her two tendencies and stay mum 10 percent of the time. Yet in psychology tests, volunteers under these circumstances stay mum 40 percent of the time.

In quantum logic, the average of zero and 20 can indeed be 40. Alice's propensities—definitely snitch if Bob snitches; probably snitch if he stays mum—partly cancel each other out if she has to juggle both eventualities in her head, so she goes with her other choice and stays mum. "These two individually good reasons interfere with each other and so make it less likely that the person will defect," says psychologist Emmanuel Pothos of City University London.

In 2009 Pothos and psychologist Jerome Busemeyer of Indiana University Bloomington devised a quantum model that reproduces the result of the psychology experiments. The underlying reason it works is that most people do not have fixed preferences. Our feelings are ambivalent and conditional on what people around us think. "We are very contextual creatures," Busemeyer says. "So there is no attitude sitting there waiting to be measured." A quantum superposition captures those mixed feelings. It does not mean our brains are literally quantum computers, as some physicists have speculated. Rather quantum physics is a useful metaphor for the fluidity of human thought.

In a way, this emerging subject of quantum cognition takes quantum physics back to its roots. In the early 20th century Niels Bohr and the other creators of the theory drew on ideas from psychology, such as the work of William James. Quantum theory came of age in a period when rationalism, which had swung in and out of intellectual fashion since the Enlightenment, held little appeal. World War I did not lend itself to optimism about the human capacity for self-betterment, and a theory that placed bounds on human knowledge appealed to Bohr and his colleagues. Yet intellectual history goes in cycles. By renewing optimism about human knowledge and behavior, perhaps today's quantum physics will help inspire a new Enlightenment and reinvigorate our hollow politics. SA

George Musser *is a contributing editor for* Scientific American *and is author of* The Complete Idiot's Guide to String Theory *(Alpha, 2008).*

MORE TO EXPLORE

Quantum Games and Quantum Strategies. Jens Eisert, Martin Wilkens and Maciej Lewenstein in *Physical Review Letters,* Vol. 83, No. 15, pages 3077–3080; October 11, 1999. http://arxiv.org/abs/quant-ph/9806088

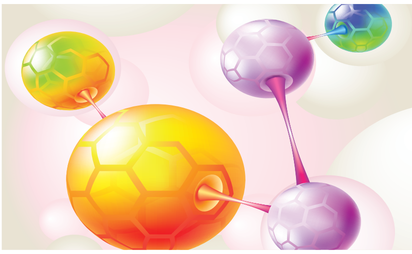
A Quantum Probability Explanation for Violations of "Rational" Decision Theory. Emmanuel M. Pothos and Jerome R. Busemeyer in *Proceedings of the Royal Society B,* Vol. 276, No. 1665, pages 2171–2178; June 22, 2009.

Does Quantum Interference Exist in Twitter? Xin Shuai, Ying Ding, Jerome Busemeyer, Yuyin Sun, Shanshan Chen and Jie Tang. http://arxiv.org/abs/1107.0681

Quantum Democracy Is Possible. Gavriel Segre. http://arxiv.org/abs/0806.3667v4

Quantum Structure in Cognition: Fundamentals and Applications. Diederik Aerts, Liane Gabora, Sandro Sozzo and Tomas Veloz. http://arxiv.org/abs/1104.3344

SCIENTIFIC AMERICAN ONLINE
For a video explanation of the classical Prisoner's Dilemma, see ScientificAmerican.com/nov2012/quantum



Chemistry

Speaker: Robert Hazen, Ph.D.

Genesis: The Scientific Quest for Life's Origins — Is life's origin an inevitable process throughout the cosmos, or is it an improbable accident, restricted to a few planets (or only one)? How does a lifeless geochemical world of oceans, atmosphere and rocks transform into a living planet? Find out how scientists use experimental and theoretical frameworks to deduce the origin of life.

The Diamond Makers

Diamond forms deep in Earth when carbon experiences searing heat and crushing pressure. Decades ago General Electric scientists learned how to mimic those extreme conditions of Earth's interior in the laboratory to make synthetic diamonds. Learn the human drama and technological advances involved in producing this coveted gem and industrial tool from carbon-rich substances.

The Story of Earth: How the Geosphere and Biosphere Co-evolved

Earth is a planet of frequent, extravagant change. Its near-surface environment has transformed over and over again across 4.5 billion years of history. Learn about the work of Dr. Hazen and colleagues that suggests that Earth's living and nonliving spheres have co-evolved over the past four billion years.

Chemical Bonding — The solid, liquid, and gaseous materials around us depend on the specific elements involved and the chemical bonds that hold those atoms together. By looking at the nature and significance of ionic, metallic and covalent bonds you'll gain a new understanding of the workings of the world around you.

Quantum Physics

Speaker: Benjamin Schumacher, Ph.D.

Private Lives of Quantum Particles

Quantum systems can exhibit all sorts of bizarre behavior. But many of these phenomena can only be observed under conditions of the strictest privacy, where systems are "informationally isolated" from the world. These are not accidental features of quantum theory. They are inescapable facts about the microscopic world: Quantum physics is what happens when nobody is looking.

2π Is Not Zero (But 4π Is) — If you rotate any geometrical shape by 360 degrees (2π radians) about any axis, you will end up with exactly the same shape. But this fact, seemingly obvious, is not true for quantum particles with spin. Learn how a rotation by 2π makes a big difference, and how it all comes down to a simple minus sign — probably the most important minus sign in all of physics. Enjoy quantum fun, demystified by Dr. Schumacher.

The Physics of Impossible Things

Physicists find it surprising useful to ponder the impossible. Using the laws of nature, assess the possibility of science fiction's favorite phenomena and explore seemingly impossible things, which while odd, are possible. Venture into the study of impossible things and come away with an affirmation of the consistent logic of nature, and renewed wonder at real phenomena.

The Force That Isn't a Force — What makes a rubber band elastic? Its entropy, the microscopic disorder of its molecules. Now, entropy may provide a clue to the most familiar and mysterious of the basic forces of nature: gravity. Explore the link between entropy and gravity, and gain fascinating and unexpected insights of contemporary theoretical physics.

Archaeology

Speaker: Kenneth Harl, Ph.D.

From Old Europe to Roman Provinces

Explore the prehistoric foundations of Scandinavia and the Viking Age from ca. 3000 B.C. to 400 A.D. From Megalithic cultures to the arrival of Indo-Europeans, to Northern Bronze Age innovations and Celtic and Roman contributions, learn the unique environmental, cultural, and social factors that create a context for the Vikings.

Great Halls and Market Towns in Viking Age Scandinavia — Using archaeological and literary sources (especially saga and Eddas), learn how the "great halls" emerged as the main focus of Scandinavia civilization. Find out how the development of towns facilitated trade and were vital for the transformation and technological advance of Scandinavian society.

Ships and Ship Building in the Viking Age — European history records the effectiveness of the fearsome Viking longship; find out the features and technologies that made it so. Based on archaeological finds, learn about the multi-millennial evolution of the longship, from linden to oak, dugout to mast and sail. Gain an appreciation for the form and function, as well as the wider implications of Norse naval mastery for three hundred years.

Warfare in the Viking Age — The Viking's applied technologies led to three centuries of robust military and economic power for Scandinavia. Discover what factors made the Vikings accomplished warriors and learn what archaeological finds tell us about Viking exploration, settlement, and development of kingdoms.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

NORWEGIAN FJORDS
JULY 5–15, 2013

The Royal Observatory and the Churchill War Room/Museum (July 4)

Take the road less traveled in London, visiting two less well known gems of the City, both uniquely fascinating and inspiring.

Courage, duty, shared sacrifice, and conviction are the foundation of the Churchill Cabinet War Rooms. Hidden in plain sight in the heart of London, a scant 600 miles from Berlin. Step back in time and discover how Churchill and Britain's government functioned in secrecy in these quarters, from the Blitz to VE Day. The furnishings, maps, and ephemera are as they were on VE day, May 8, 1945. Hear the stories and imagine life under bombardment in the simple and inspiring environment of the Cabinet War Rooms.

Are you the precise type? Are you a fan of Google maps or GPS? Or Cutty Sark? Join us on a tour of maritime Greenwich, where our prime objective is visiting the Royal Observatory, Greenwich, home of the Prime Meridian of the World and Greenwich Mean Time. Stroll a deeply historic corner of London significant in local, national, and international culture. See the Royal Observatory, the National Maritime Museum, the tea clipper Cutty Sark, and the Royal Naval College. Master the lingo of time — UT0, UT1, UTC, and GMT. Stand astride two hemispheres on the Prime Meridian, a moment sure to be recorded on your timeline.

Stonehenge and Bath (July 3)

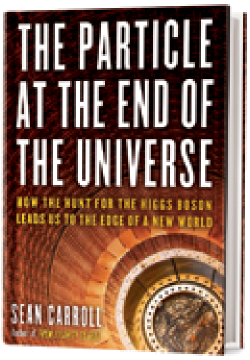
Pass a day on the Salisbury Plains and Somerset Hills, absorbing the history of two spots with ancient cultural roots.

Mute, mysterious, and megalithic, Stonehenge calls to us across the millennia. We'll respond, and walk the site in its details. Learn the significant geography, the archaeological and astronomical background, and the key stone names. But those are just the facts — the memories and true meaning of Stonehenge will be up to you.

Bath beckons the seasoned traveler. People are drawn to Bath to see its honey-colored Bath limestone buildings, and to explore its 2,000 year history as a place of relaxation and restoration. Plumb the details and nuances of Bath's fusion of architecture, culture, and history in a city with many echoes of and homages to the ancient world, while embodying the Georgian worldview.

For more info please call 650-787-5665 or log on to ScientificAmerican.com/Travel

BOOKS



The Particle at the End of the Universe: How the Hunt for the Higgs Boson Leads Us to the Edge of a New World

by Sean Carroll. Dutton, 2012 ($27.95)

For those wishing to understand the nitty-gritty of how physicists at CERN's Large Hadron Collider found the new entity-that-may-be-the-Higgs-boson, here is a timely account from physicist and author Carroll. Starting with the dramatic July 4, 2012, announcement of the new particle, then going briefly back in time to the Greek philosophers—the first to suggest that all matter was composed of tiny, elemental pieces—he reconstructs the global hunt for the particle that gives all others their mass, stopping to explain basic physics along the way.

Drinking Water: A History

by James Salzman. Overlook Press, 2012 ($27.95)

Salzman's account of drinking water makes the liquid seem as mythic as the fountain of youth. He explores the engineering, politics and health implications surrounding humans' quest for water, as well as the toxins and changing climate that threaten our supply. The history includes how physician John Snow methodically traced an 1854 cholera outbreak to a single water pump in London, New York City's evolution from a disease-ridden metropolis to one that boasts about its tap water, and the innovative technologies that may avert global water poverty.

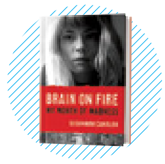
—Marissa Fessenden

The Logician and the Engineer: How George Boole and Claude Shannon Created the Information Age

by Paul J. Nahin. Princeton University Press, 2012 ($24.95)

Grab a pencil and paper to work through the puzzles peppering this engaging account of Boolean logic and computing through the work of 19th-century mathematician George Boole and 20th-century electrical engineer Claude Shannon. Math writer and emeritus professor Nahin assumes some rudimentary knowledge but expertly explains concepts such as relay circuits, Turing machines and quantum computing. Reasoning through the problems and diagrams will give persistent readers genuine aha moments and an understanding of the two revolutionaries who helped to lay the foundation of our digital world.

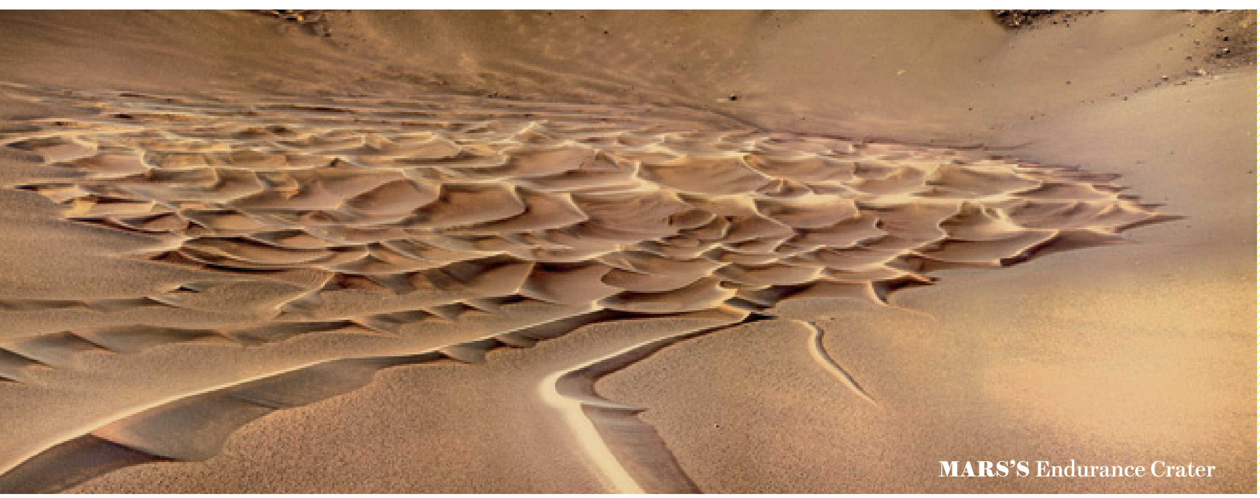
—Marissa Fessenden



Brain on Fire: My Month of Madness

by Susannah Cahalan. Free Press, 2012 ($25)

A young *New York Post* reporter contracts a rare brain disorder, recovers against the odds, then puts her restored mind to use investigating the disease's medical underpinnings. Cahalan's account is swift and haunting and holds relevance beyond her dramatic case. Researchers are recognizing that autoimmune diseases of the nervous system—hers is called anti-NMDA receptor encephalitis—are more common than previously thought. As barriers collapse between immunology, neurology and psychiatry, investigators are gaining a clearer understanding of the roots—and true nature—of mental illness.



MARS'S Endurance Crater

ALSO NOTABLE

BOOKS

Planetfall: New Solar System Visions, by Michael Benson. Abrams, 2012 ($55)

The Signal and the Noise: Why So Many Predictions Fail—But Some Don't, by Nate Silver. Penguin Press, 2012 ($27.95)

Chasing Doctor Dolittle: Learning the Language of Animals, by Con Slobodchikoff. St. Martin's Press, 2012 ($25.99)

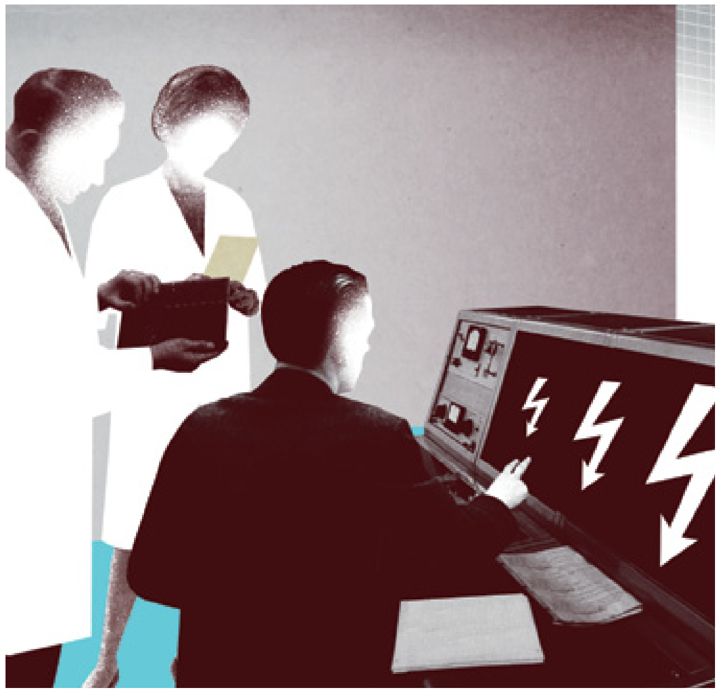
COURTESY OF NASA/JPL-CALTECH/MICHAEL BENSON *Kinetikon Pictures*

COMMENT AT ScientificAmerican.com/nov2012

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

Shock and Awe

Replicating Milgram's shock experiments reveals not blind obedience but deep moral conflict



In 2010 I worked on a *Dateline NBC* television special replicating classic psychology experiments, one of which was Stanley Milgram's famous shock experiments from the 1960s. We followed Milgram's protocols precisely: subjects read a list of paired words to a "learner" (an actor named Tyler), then presented the first word of each pair again. Each time Tyler gave an incorrect matched word, our subjects were instructed by an authority figure (an actor named Jeremy) to deliver an electric shock from a box with toggle switches that ranged in 15-volt increments up to 450 volts (no shocks were actually delivered). In Milgram's original experiments, 65 percent of subjects went all the way to the end. We had only two days to film this segment of the show (you can see all our experiments at http://tinyurl.com/3yg2v29), so there was time for just six subjects, who thought they were auditioning for a new reality show called *What a Pain!*

Contrary to Milgram's conclusion that people blindly obey authorities to the point of committing evil deeds because we are so susceptible to environmental conditions, I saw in our subjects a great behavioral reluctance and moral disquietude every step of the way. Our first subject, Emily, quit the moment she was told the protocol. "This isn't really my thing," she said with a nervous laugh. When our second subject, Julie, got to 75 volts and heard Tyler groan, she protested: "I don't think I want to keep doing this." Jeremy insisted: "You really have no other choice. I need you to continue until the end of the test." Despite our actor's stone-cold authoritative commands, Julie held her moral ground: "No. I'm sorry. I can just see where this is going, and I just—I don't—I think I'm good. I think I'm good to go." When the show's host Chris Hansen asked what was going through her mind, Julie offered this moral insight on the resistance to authority: "I didn't want to hurt Tyler. And then I just wanted to get out. And I'm mad that I let it even go five [wrong answers]. I'm sorry, Tyler."

Our third subject, Lateefah, became visibly upset at 120 volts and squirmed uncomfortably to 180 volts. When Tyler screamed, "Ah! Ah! Get me out of here! I refuse to go on! Let me out!" Lateefah made this moral plea to Jeremy: "I know I'm not the one feeling the pain, but I hear him screaming and asking to get out, and it's almost like my instinct and gut is like, 'Stop,' because you're hurting somebody and you don't even know why you're hurting them outside of the fact that it's for a TV show." Jeremy icily commanded her to "please continue." As she moved into the 300-volt range, Lateefah was noticeably shaken, so Hansen stepped in to stop the experiment, asking, "What was it about Jeremy that convinced you that you should keep going here?" Lateefah gave us this glance into the psychology of obedience: "I didn't know what was going to happen to me if I stopped. He just—he had no emotion. I was afraid of him."

Our fourth subject, a man named Aranit, unflinchingly cruised through the first set of toggle switches, pausing at 180 volts to apologize to Tyler—"I'm going to hurt you, and I'm really sorry"—then later cajoling him, "Come on. You can do this.... We are almost through." After completing the experiment, Hansen asked him: "Did it bother you to shock him?" Aranit admitted, "Oh, yeah, it did. Actually it did. And especially when he wasn't answering anymore." When asked what was going through his mind, Aranit turned to our authority, explicating the psychological principle of diffusion of responsibility: "I had Jeremy here telling me to keep going. I was like, 'Well, should be everything's all right....' So let's say that I left all the responsibilities up to him and not to me."

Human moral nature includes a propensity to be empathetic, kind and good to our fellow kin and group members, plus an inclination to be xenophobic, cruel and evil to tribal others. The shock experiments reveal not blind obedience but conflicting moral tendencies that lie deep within. SA

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Illustration by Mario Wagner


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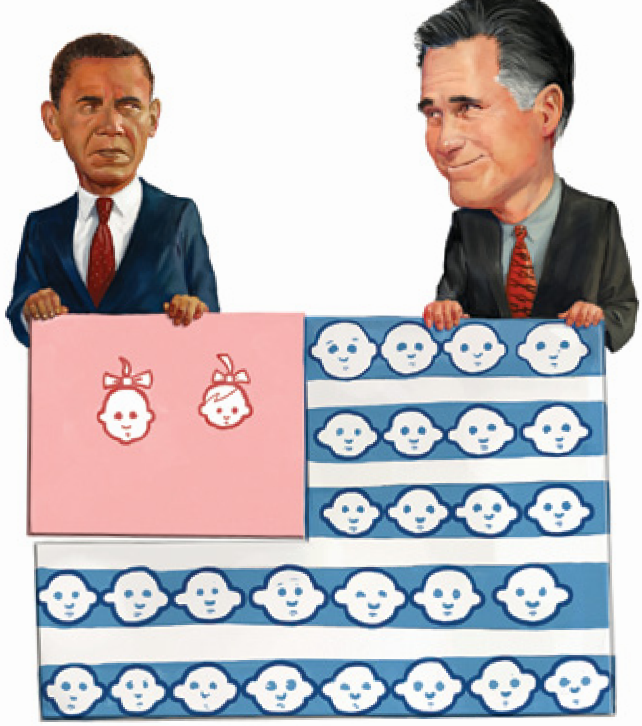
The ongoing search for fundamental farces



Steve Mirsky has been writing the Anti Gravity column since Derek Jeter had a total of 12 base hits in the major leagues. He also hosts the *Scientific American* podcast Science Talk.

A Trivers Runs through It

As a talking equid once advised, go right to the source and ask the horse

I like evolution. It made me the man I am today. But most Americans do not accept evolution, and the percentage is even lower among conservatives. So I was surprised when, on August 27, a deputy managing editor of the *National Review*—a conservative magazine that has published numerous evolution deniers—cited evolutionary theory as a reason that women should vote for Willard Mitt Romney for president.

Kevin D. Williamson wrote, "It is a curious scientific fact (explained in evolutionary biology by the Trivers-Willard hypothesis—*Willard,* notice) that high-status animals tend to have more male offspring than female offspring, which holds true across many species, from red deer to mink to *Homo sap.*"

Williamson notes that Romney has five sons, a bunch of male grandsons and is "basically a tribal chieftain." And Barack Obama? "Two daughters. May as well give the guy a cardigan. And fallopian tubes." Based on the sex ratios of the two men's progeny, he then concludes, "From an evolutionary point of view, Mitt Romney should get 100 percent of the female vote. *All of it.* He should get Michelle Obama's vote."

So I called Robert Trivers. Of the Trivers-Willard hypothesis and numerous other groundbreaking propositions that have made Trivers a legendary character in evolutionary theory and "one of the great thinkers in the history of Western thought," according to experimental psychologist and popular author Steven Pinker of Harvard University.

I told Trivers that Williamson's article tried to make the case from Trivers-Willard that all women should vote for Romney. He responded, "HAHAHAHAHA!"

In their 1973 paper Trivers and Willard sum it up: "Natural selection should favor parental ability to adjust the sex ratio of offspring produced according to parental ability to invest," with investment including all care for the progeny, from fertilized egg to independence. "The best evidence was in red deer," Trivers explained on the phone, "where dominant females produce 60 percent sons. But investment in mammals has a simple logic because usually the male ain't doing s—." In this polygynous species, where a single male's harem can number 20 females, a dominant female's strong sons have a big advantage over weaker males that may spend their lives nookie-free.

When he stopped laughing, Trivers continued, "Maybe the guy should be saying that all women should try to f— [Romney]. Look, the f—er's rich. Can you f— him and get some of the money? Or are you just voting for him? They're two different decisions."

Just as an exercise, Trivers did some analysis of Trivers-Willard in regard to Romney and Obama: "There's no way of looking at the sex ratios of progeny of these two couples and predicting anything about their relative superiority over time. It would be better put as an evolutionist arguing about the five-versus-two ratio [of the total number of children born to each candidate].

"They [women] should all want a man with money. That's so obvious we don't need to talk about the sex ratio of the progeny. But then he [Williamson] wants to double down: hey, he [Romney] produced five sons, so that proves he's the ultimate on that side of the coin. But by the same logic there's an ultimate on the other side of the coin who's a female specialist. If Obama had *five* girls, then we could line it up and see that they [the total number of progeny over the long term] are identical." Williamson's invocation of Trivers-Willard would thus allow for a more balanced analysis if Romney were running for mayor of Anatevka against *Fiddler on the Roof*'s Tevye "I have five daughters" the Milkman.

Trivers also pointed out that the *National Review* citation ignored the role of the candidates' mates in the production of progeny. Note to Williamson: females also contribute genetic material in reproduction.

Nevertheless, kudos to the *National Review* for attempting to wrestle with evolutionary theory, even if Williamson took to it with all the dexterity of a man in a straitjacket. By the way, Trivers's latest book is entitled *The Folly of Fools: The Logic of Deceit and Self-Deception in Human Life.* When I'm done with my copy, it's all yours, Kevin. SA

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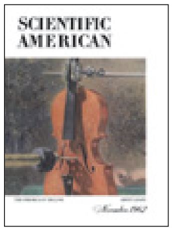
Illustration by Matt Collins

50, 100 & 150 Years Ago compiled by Daniel C. Schlenoff

Innovation and discovery as chronicled in *Scientific American*



November 1962

Socially Deprived

"Our investigations of the emotional development of our subjects grew out of the effort to produce and maintain a colony of sturdy, disease-free young animals for use in various research programs. By separating them from their mothers a few hours after birth and placing them in a more fully controlled regimen of nurture and physical care, we were able both to achieve a higher rate of survival and to remove the animals for testing without maternal protest. Only later did we realize that our monkeys were emotionally disturbed as well as sturdy and disease-free. —Harry F. Harlow and Margaret Kuenne Harlow"

Violins Today

"The well-developed science of acoustics is applicable to the understanding and making of violins. Without ignoring the precious heritage of centuries, the violin maker should become more conscious of the science of his instrument, and the acoustical physicist should see that here is a real challenge to his discipline. We really ought to learn how to make consistently better instruments than the old masters did. If that challenge cannot be fulfilled, we should at the very least find out the reasons for our limitations."

November 1912

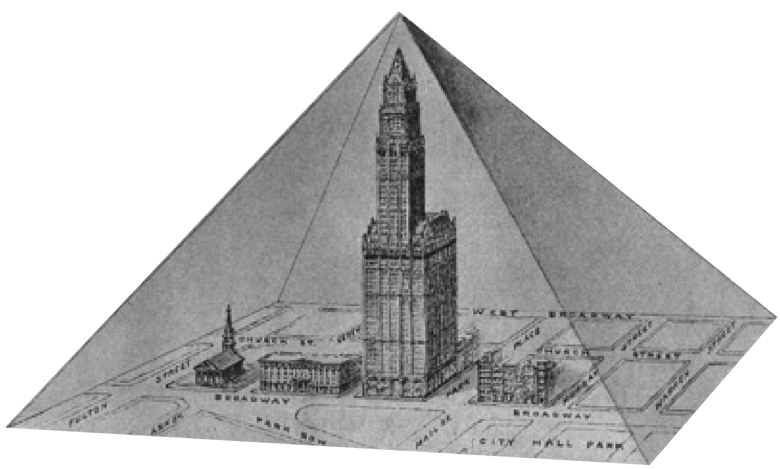
Panama Canal

"Shall we be stretching the point too far when we say that the conquest of the Isthmus of Panama is a feat of the arms of peace, as brilliant and as difficult as any ever accomplished by the arms of war? The fact that the canal will be ready for traffic over a year ahead of the time appointed, tells the story of the army's successful handling of this, the world's greatest engineering work."

The Panama Canal officially opened almost two years later, on August 15, 1914. For a slide show of the ongoing work on the canal, see ***www.ScientificAmerican.com/nov2012/panama-canal***

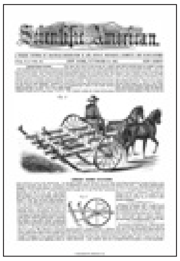
Curtiss on His Flying Boat

"It is not difficult to understand why a sheet of water affords an ideal aerodrome. The aviator does not have to run along a given course to start, and he can always head into the wind. Altogether, it is much easier and safer to start and alight on the water. The new 'flying boat' gives us the advantages to be found in a boat with its large surplus of buoyancy, seaworthiness and protection for the aviators. The Curtiss 'flying boat' will



TWO YEARS before the Panama Canal opened, at least 20 million cubic yards of earth-slide material had to be removed from the Culebra Cut (a major dig site)—enough to make a pyramid taller than the unfinished Woolworth Building, 1912

SCIENTIFIC AMERICAN, VOL. CVII, NO. 19; NOVEMBER 9, 1912 ride as rough a sea, either under power or adrift, as any motor boat of its size, and flies as well as any aeroplane of equal proportions; so that the combination gives us the advantages of the motor boat and the aeroplane. There are no limitations to the development of this type of machine. —Glenn Curtiss"



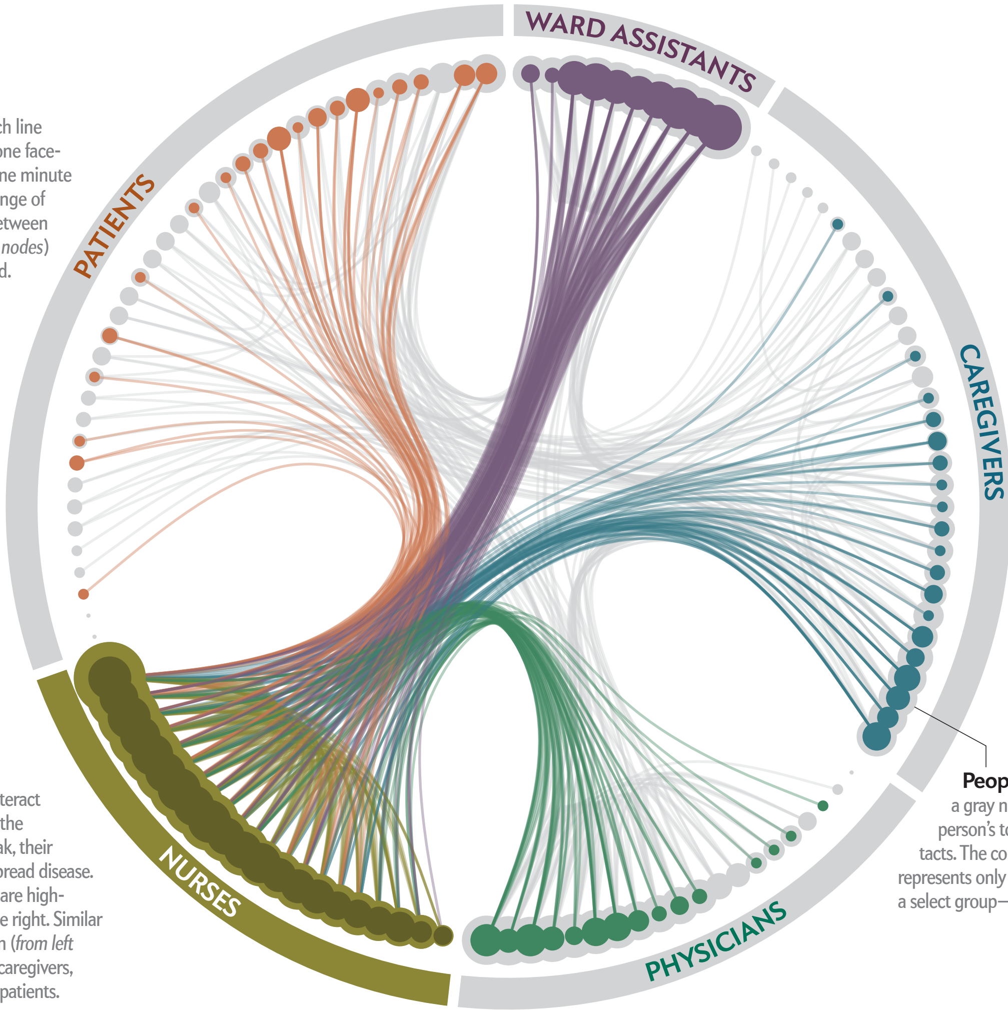
November 1862

Plastics for Toys

"Among the varied products of that wonderful substance—vulcanized india-rubber—a new American art has been developed in its application to the manufacture of elastic toys. Tons of them are made annually in the Wiccopee factory, situated on the Fishkill, near Matteawan, N.Y. They are as superior to the old German toys in every respect as can well be imagined. Many of the dolls appear to be clothed in velvet and fine woolen cloth. The drapery, however, is formed of india-rubber; the velvet and cloth imitations being produced by dusting silk and woolen flocks upon the parts, which are prepared with a peculiar varnish to make the flocks adhere."

Elections

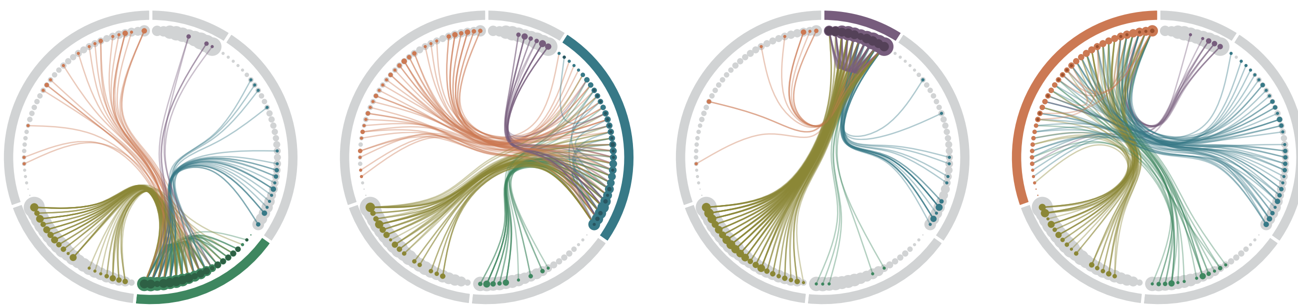
"In sight of our office window, in the City Hall Park, is the recruiting tent of Captain Hogan, a brave fighting Irishman who commanded a battery in the seven days' battle in front of Richmond. We met the captain the other morning on his round of duty, and enquired how he got on with recruiting. 'Badly,' he replied, and assigned as a chief reason that the politicians of both parties were hindering enlistments for fear some of their followers might get off to the war before election. The captain says those miserable fellows would sell out St. Paul and all the apostles if they could only get into office."



Interactions Each line represents at least one face-to-face contact of one minute or more, within a range of about 1.5 meters, between individuals (*circular nodes*) in the pediatric ward.

Groups Nurses interact with people all over the ward—in an outbreak, their movements could spread disease. Nurses' interactions are highlighted in color at the right. Similar maps below focus on (*from left to right*) physicians, caregivers, ward assistants and patients.

People The size of a gray node reflects that person's total number of contacts. The colored inner circle represents only the contacts with a select group—nurses, in this case.



Tag—You're Sick

Patterns of personal contact in a hospital reveal true pathways of transmission

Hospitals shouldn't make you sicker. But plenty of people acquire illnesses while hospitalized—in some countries, such so-called nosocomial infections afflict more than 10 percent of patients.

To investigate transmission pathways, European researchers fitted 119 people in a pediatric ward with radio-frequency identification (RFID) badges. The tags registered face-to-face interactions—and the potential spreading of airborne pathogens.

Nurses interacted with the widest variety of people across the ward—patients, doctors, other nurses, and so on. The study indicates that nurses should take priority in strategies for preventing or controlling hospital outbreaks. *—John Matson*

SCIENTIFIC AMERICAN ONLINE
Explore data for all the interactions at ScientificAmerican.com/nov2012/graphic-science

SOURCE: "CLOSE ENCOUNTERS IN A PEDIATRIC WARD: MEASURING FACE-TO-FACE PROXIMITY AND MIXING PATTERNS WITH WEARABLE SENSORS," BY LORENZO ISELLA ET AL., IN *PLoS ONE*, VOL. 6, NO. 2; FEBRUARY 28, 2011

Graphic by Jan Willem Tulp