SPACE SCIENCE
Mountain-Climbing **MARS ROVER**

MEDICINE
Vaccine Clues from **HIV SURVIVORS**

ARTIFICIAL INTELLIGENCE
Seeing the Future with **MACHINE LEARNING**

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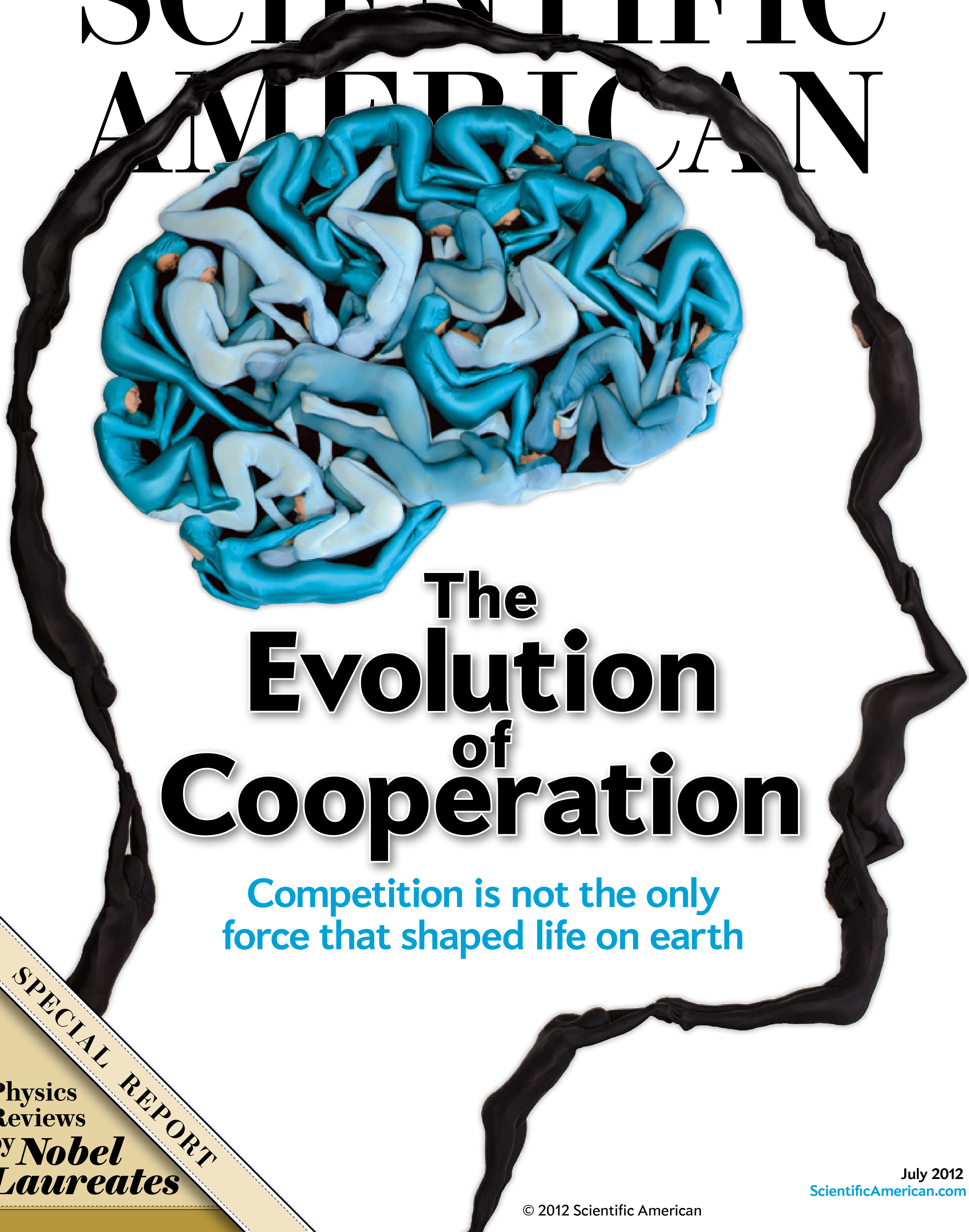

The Evolution of Cooperation

Competition is not the only force that shaped life on earth

SPECIAL REPORT

Physics Reviews by *Nobel Laureates*

July 2012
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But is that loud enough
for a skeptic?
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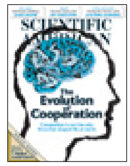
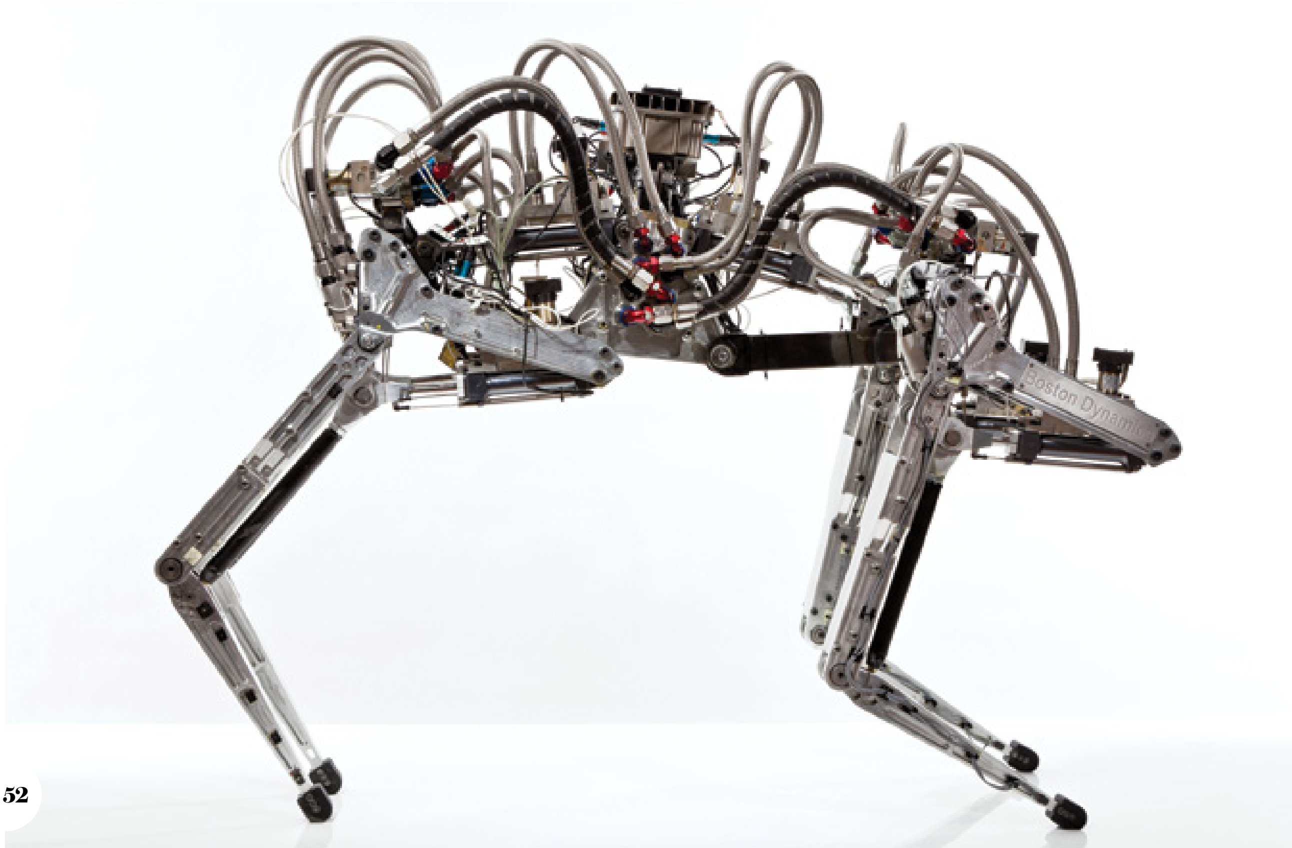
July 2012 Volume 307, Number 1

ON THE COVER



Although competition is typically viewed as the driving force of evolution, it did not act alone. Cooperation, too, has profoundly shaped the evolution of life on earth—from single-celled organisms to insects and humans. We *Homo sapiens* are especially cooperative, thanks to our peerless ability to communicate using language. Photograph by Stephen Wilkes.



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Photograph by Andrew Hetherington

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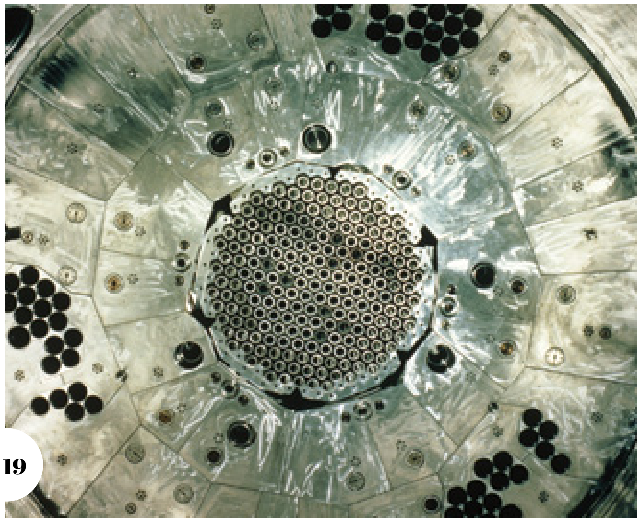

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ON THE WEB

Solutions for the Freshwater Crisis

New technologies are helping to purify water contaminated by pathogens or polluted with chemical agents, such as those used to extract fossil fuels from the earth in hydraulic fracturing, aka fracking.
Go to www.ScientificAmerican.com/jul2012/water

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

Succeeding Together

It is common for us to focus on the competitive aspects of the well-worn phrase "survival of the fittest." As it turns out, however, we sell nature short when we do so. Fitness is not simply a cutthroat matter of outperforming others to survive and reproduce—thus passing along those successful genes. As you will learn in this issue's cover story, "Why We Help," by Martin A. Nowak, cooperation among members of groups, from single-celled amoebas to the complex assemblages found in mammals, has helped shape the evolution of all of life on earth in profound ways. Individuals may engage in various flavors of cooperation, from discharging a beneficial duty for kin to performing selfless actions for the greater good. It may (or may not) surprise you to learn that people earn a unique place among species as the most mutually helpful of all. Nowak calls the phenomenon the "snuggle for survival." For more, turn to page 34.

Surely science, which can involve teams of researchers from around the globe working on projects, is one of humankind's great collaborative endeavors. Yet society also enjoys shining a spotlight on those individuals whose contributions have been most worthy of our group's admiration. In our special section "Nobel Pursuits," timed for the annual gathering in which laureates and young scientists (cooperatively) share insights at Lindau near Germany's Lake Constance, we offer a selection of excerpts from the many feature articles by Nobel Prize–winning authors who have appeared over the years in the pages of *Scientific American*. Beginning on page 62, associate editors John Matson and Ferris Jabr frame the section with an overview of the key questions in physics today in honor of the topic theme chosen for the 62nd annual Lindau meeting.

Last, I wanted to mention a recent travel highlight. I was a panel moderator at Neuromagic 2012, a conference that brought together neuroscientists and magicians to the Island of Thought, also called San Simón, in the bay of Vigo, Spain. In a few days this remarkable group of students of human behavior and the mind advanced discussion in several important areas—teamwork at its best. SA

SCIENCE IN ACTION

Science Fair Winners

Following the *Scientific American*-sponsored $50,000 Science in Action Award announced last month comes the rest of the Google Science Fair category winners, to be announced on July 23. This is the second year of the global online competition, which awards students in three age groups from 13 to 18, and I am delighted to be one of the judges. Look for our coverage at www.ScientificAmerican.com.

—M.D.

Illustration by Nick Higgins


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From checkered flags on the ground, to radar to digital to satellites, the steady advance of air traffic control has been led by innovators from Lockheed Martin and its legacy companies. Today, 75 percent of America's air traffic is controlled by systems designed, built, and deployed by Lockheed Martin. Flying has become safer and more efficient than ever before. And millions of passengers arrive at their destinations, never knowing that they've flown there on a 60-year history of achievement.
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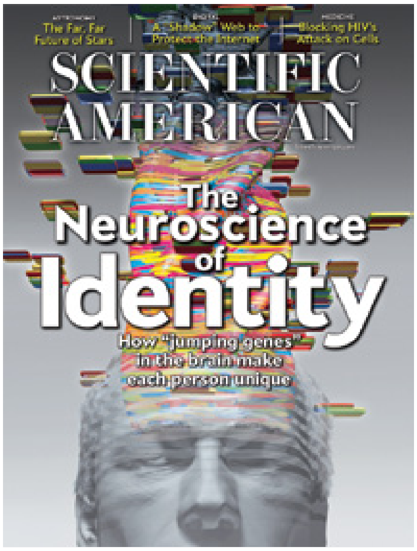

March 2012

MIND'S WHY

In describing their conclusions that DNA segments, or jumping genes, that can copy themselves into different parts of the genome may be the cause of the uniqueness of individual brains in "What Makes Each Brain Unique," Fred H. Gage and Alysson R. Muotri misrepresent the degree of similarity expected between the brains of identical twins. Their work does reveal an intriguing source of genetic variation between such brains, the significance of which remains to be elucidated.

Yet the authors gloss over the fact that all brains, genetically identical or otherwise, are almost certainly quite distinct as a result of inherent variation in neural stem cell divisions, cell migration events and neural circuit formation. Such variation is created by the unique, probably often random, cellular and experience-dependent interactions that occur during the development of any given brain.

NICHOLAS GAIANO
Johns Hopkins University School of Medicine

Having worked with start-ups and early-stage businesses my entire career, I have participated in many debates about whether entrepreneurs are born or made. What entices otherwise employable people to work for practically—maybe explicitly—nothing beyond the lottery system known as stock options (the tool Silicon Valley uses to lure young engineers into working crazy hours with no guarantees)? Now I learn that with jumping genes, natural selection is "rolling the dice" to build brains to meet the challenges of ever changing conditions. Yep, that sounds like an entrepreneur.

MICHAEL J. CONNELLY
President emeritus
New York Venture Capital Forum

"Must solutions to the black cloud of depression always be medicinal?"

BLAIR T. JOHNSON AND LINDA S. PESCATELLO
UNIVERSITY OF CONNECTICUT

STAR BRIGHT

In "The Far, Far Future of Stars," Donald Goldsmith states that the luminosity of a star richer in heavy elements declines because of opacity of its outer layers. Then, in the next sentence, he goes on to say that "the lower luminosity means that the star consumes its nuclear fuel at a lower rate." So what is it, opacity or lower rate?

Also, one expects that the trapping of radiation by the outer layers would cause the temperature to increase and, consequently, the fusion rate to increase as well. So what is going on?

DOV ELYADA
Haifa, Israel

GOLDSMITH REPLIES: Stars produce energy in their cores, which passes to their surfaces and radiates into space. The lower luminosity results from a higher opacity, which hinders the passage of radiation. A lower luminosity also implies a lower rate of energy production and thus a slower consumption of nuclear fuel. The higher opacity that leads to a greater trapping of radiation produces complex effects in a star's atmosphere, including a possible increase in its size and temperature, but it is the temperature in the core, not in the atmosphere, that determines the star's rate of energy production.

DEPRESSION RELIEF

"Lifting the Black Cloud," by Robin Marantz Henig, succinctly and correctly sums up the state of evidence regarding the efficacy of antidepressant medications in saying that they "leave a lot to be desired."

There are other alternatives. High-quality randomized controlled trials have shown that aerobic exercise reduces depressive symptoms in cancer survivors and in other populations. In contrast to the common side effects of antidepressants—such as sexual dysfunction, headaches, insomnia and nausea—those of exercise are a pure delight—enhanced libido, better sleep, decreased body fat, longer life, increased strength and endurance, and more. Exercise has the added benefit of low cost and may be modified to match individual needs. Must solutions to the black cloud of depression always be medicinal?

BLAIR T. JOHNSON
LINDA S. PESCATELLO
University of Connecticut

One of the possible new treatments discussed in the article targets inflammation. Immune system–modulating products of this type can have the unwanted side effect of allowing latent infections to resume activity. And not just latent infections but unsuspected active infections producing inflammation might be involved, so interfering with the immune system will have consequences. Some investigators are looking at the connection between microbes and mental illness. Syphilis is well known as an agent of psychiatric symptoms, and a number of other germs may be as well. In those cases, you would want to recognize and treat the infection, too.

LINDA FINN
Gainesville, Ga.

FAULTY PHRASE

"A Neglect of Mental Illness," by the Editors [Science Agenda], states that "all of us should get over the stigma we still tend to attach to" conditions of mental illness.

Was this an intentionally ironic play on words? Isn't the typical, uneducated and frustrating response to mental illnesses, such as depression, to believe sufferers should just "get over it"? Mental illness is not something one can just get over, nor can intolerance, misunderstanding and fear be overcome that way.

Acceptance and a positive, proactive approach to mental illness can be achieved

KUWAIT PRIZE 2012
Invitation for Nominations

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

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

The Prizes for 2012 will be awarded in the following fields:

1.	Basic Sciences	: Molecular Biology
2.	Applied Sciences	: Energy
3.	Economic and Social Sciences	: Management Science
4.	Arts and Literature	: Theatre
5.	Arabic and Islamic Scientific Heritage	: Arabic and Islamic Scientific Heritage

Foreground and Conditions of the Prize:

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

Inquiries concerning the KUWAIT PRIZE and nominations including complete curriculum vitae and updated lists of publications by the candidate with **four copies** of each of the published papers should be received before **1/12/2012** and addressed to:

The Director General

The Kuwait Foundation for the Advancement of Sciences - P.O. Box: 25263, Safat - 13113, Kuwait
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through education. This article not only missed a teachable moment but did so by opting for a phrase that is universally unappreciated by those suffering mental illness.

Marie Smith
via e-mail

NEEDED NUISANCE

In "Time to Kill Off Captchas" [TechnoFiles], David Pogue argues that variants of the Captcha system used to filter out hacker and spammer programs (bots) from Web sites, including the newer reCaptcha, waste too much of users' time.

ReCaptcha successfully blocks hundreds of spambot attacks on my guest book page daily. No legitimate visitor to the site has ever complained to me about it. I am also 63 years old, wear bifocals and usually surf the Internet on an eight-year-old laptop with a 1,280- by 800-pixel screen. It is very rare that I encounter a Captcha image I cannot decipher, and I almost never have to refresh the image more than once to get one. This leaves me puzzled at the complaints of younger Web surfers who have, presumably, better eyes and better equipment.

So far the only countering move the spammers have come up with I am aware of is to hire Bangladeshis to sit at terminals all day solving Captchas. Because that costs them money, it removes the main incentive for spamming. The problem is thus much smaller and manageable with simple filtering. Further, if anyone ever did come up with an automated solution for Captchas, they could file for a patent on their algorithm and generate more income by licensing it for legitimate optical character recognition use than their spamming activities could hope to gain them.

It would be nice if there was another, better, less bothersome solution to the problem of spambots, but for now there isn't. We use Captchas because they work. They are not the only solution against spambots, but they are the most effective one. Until a way is found to block spam messages or identify them by their source (which would require a major revision of the Internet protocols), we are going to be seeing Captchas. At this time, the alternative is much worse.

Jerry Hollombe
via e-mail

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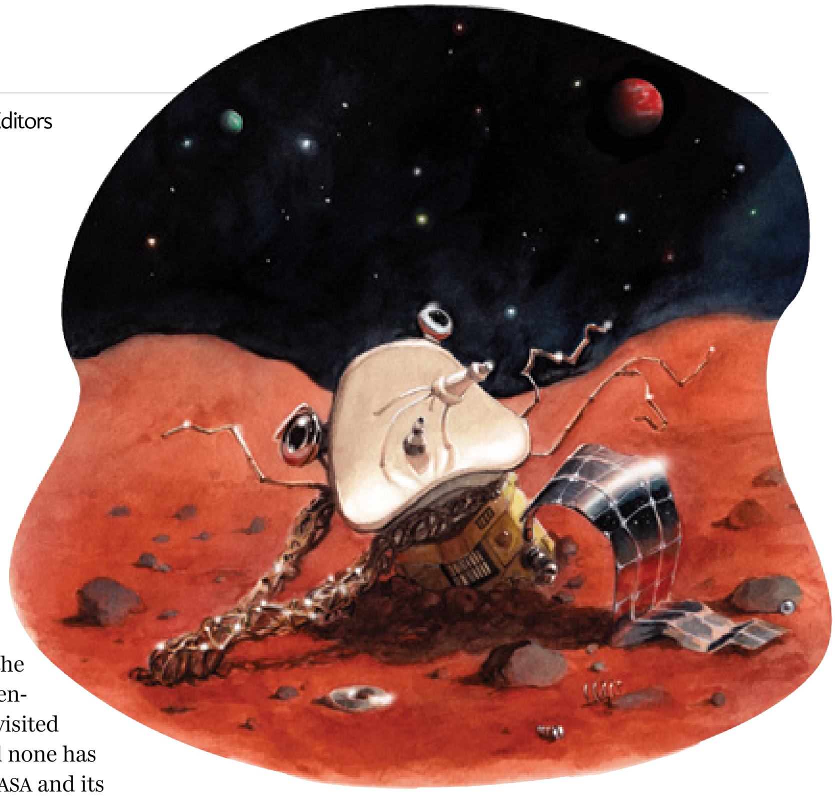

To the Moons, NASA

Planetary science is NASA's most successful and inspirational program. It should not be gutted

Last year, after a lengthy, circuitous journey through the solar system, a NASA probe known as MESSENGER entered into orbit around Mercury. No spacecraft had visited the innermost planet in more than three decades, and none has paid an extended visit. With MESSENGER's arrival, NASA and its international counterparts now have spacecraft stationed at Mercury, Venus, Mars and Saturn—not to mention Earth and the moon. Two more NASA craft are en route to Jupiter and Pluto; yet another ought to reach the dwarf planet Ceres in 2015. Humankind's presence has never stretched so far.

It could stretch farther still, with robots spying down on bizarre moons that might harbor alien life or on the little-understood outermost planets. An even more novel campaign would ferry Martian rocks back to Earth for analysis. NASA had been on track to begin such an ambitious project, but alas, political maneuvering recently forced the space agency to scrap its plans.

The president's proposed budget for 2013 includes drastic cutbacks to planetary science of more than 20 percent that could derail many future missions. Such erratic handling of NASA threatens the nation's steady progress of solar system exploration, which is hypersensitive to the vicissitudes of budget politics.

Sending robotic missions out into the solar system requires years of preparation. Interplanetary probes depend on cutting-edge technologies that are developed and tested over time. And flight plans often demand a well-timed launch during a brief planetary alignment. Nurturing these complex missions calls for patience and a steady hand. That is why a group of planetary scientists draws up a blueprint for exploration every 10 years or so under the auspices of the National Research Council. This advisory panel issued its most recent report last year, which prioritizes the missions and objectives that will yield the most science per dollar. Shaking up the planetary science division now, for a relatively meager savings of $300 million, would force NASA away from these sensible, well-defined goals.

The most severe cuts were to Mars exploration, long a U.S. specialty. NASA was to begin the process of returning samples from the Red Planet during a joint 2018 mission with the European Space Agency (ESA). That campaign, perhaps the most important flagship project this decade, appears to be dead. With the release of the president's budget request, NASA had to concede that it would withdraw from the 2018 Mars mission, as well as from a 2016 launch, also in collaboration with ESA, of an orbiter that would have sought out the origins of trace gases in the Martian atmosphere. Both missions would have made significant progress toward answering the question of whether Mars was ever habitable.

The budgetary ax also threatens to push other top targets for exploration further into the distance. Foremost among them is Jupiter's moon Europa, which scientists suspect holds an internal ocean that could harbor life. The ice giants Uranus and Neptune have only been investigated in fleeting flybys. These worlds will remain unsolved puzzles without a reversal of regressive policies.

In a fraught fiscal climate, NASA should focus on what it does best and on what offers the best return on investment. Solar system exploration meets both criteria: the U.S. has long led the interplanetary charge, and the resulting scientific benefits have come at a relative bargain. This year NASA's planetary science program cost about $1.5 billion—less than what NASA spent designing a congressionally mandated rocket, the Space Launch System, which appears more likely to satisfy aerospace contractors than to aid the cause of space exploration. Such directives from lawmakers all too often land in NASA's lap without the funds to carry them out.

A mere fraction of a cent from every tax dollar seems a small price to pay for the extension of humanity's robotic reach to distant worlds—one of our greatest accomplishments as a nation, not to mention as a technological species. If planetary science must suffer, the reduction should be phased in gradually so that scientists can try to soften the disruption to long-term plans.

As this issue went to press, an appropriations bill was pending in the U.S. House of Representatives that would restore some funds to planetary science. Congress should take this first step toward stabilizing the program—and toward investing in planetary exploration at a level commensurate with its proven value. SA

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Illustration by Scott Brundage

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Francis Collins is director of the National Institutes of Health.

How to Fulfill the True Promise of "mHealth"

Mobile devices have the potential to become powerful medical tools

As a volunteer in a trial of mobile health technology, I can attest that it's incredibly cool to pick up your iPhone, fire up an application to monitor your heart rate and rhythm, and then beam your ECG reading to a cardiologist halfway around the globe. As a physician-scientist, I also know that cool technology is not necessarily synonymous with good science or sound health practices and that therein lies a challenge.

The use of cell phones and wireless sensors to gather and access health data has grown quickly in recent years. Popular mHealth apps are used for counting calories, gauging nutrition, tracking workouts, calculating body mass index and quitting smoking. These worthy efforts pale next to the potential of mHealth to aid in medical research and health care.

Mobile devices offer remarkably attractive low-cost, real-time ways to assess disease, movement, images, behavior, social interactions, environmental toxins, metabolites and a host of other physiological variables. Many mHealth technologies could be put to highly innovative uses in biomedical research; at the same time, biomedical research could help build the foundation of evidence that so many mHealth applications currently lack.

Because mobile devices are miniaturized and require little energy to operate, they have the power to bring the research laboratory to the patient in ways never before possible. For instance, clinical trial participants can avoid the inconvenience of visiting research facilities, writing down their daily activities or wearing clunky monitors. Scientists would also get higher-quality data because written diaries and questionnaires about exercise, diet, pain, and so forth, are notoriously unreliable. Real-time continuous biological, behavioral and environmental data can greatly improve understanding of the underlying cause of disease. Combining mHealth data with GPS data could also lead to early detection and warning systems for outbreaks of illnesses related to environmental exposures or infectious agents.

Wireless sensors could help scientists keep track of sleep patterns at home, instead of their having to rely on lab-based studies or self-reporting. Doctors could monitor blood pressure during daily activities, which is when it matters most, rather than in a clinic. Washable tattoos embedded with nanosensors could take blood glucose and sodium readings for transmission via a smartphone.

To make all this happen, health researchers, technology developers and software designers must pull together to find ways of evaluating new technologies. The National Institutes of Health is working to build the interdisciplinary research capacity needed to establish an evidence base for the benefits and risks associated with mHealth technologies.

Maintaining privacy and security of health data is a challenge that calls for research. How do we protect trial participants and ordinary consumers without adversely affecting research and quality of care? Who will set rules for privacy of mHealth data? Who will provide protections if privacy is breached?

We must also learn how people are actually using mHealth in their everyday lives. I suspect that, right now, the majority of users are much like me, treating their new apps as gee-whiz toys rather than as valuable tools for improving their health. I am convinced, however, that the real potential of mHealth lies with much more committed users, such as the children with type 1 diabetes who took part in a yearlong, case-control study of wireless technologies to monitor and manage blood glucose levels. That study, published in *Diabetes Care,* showed that youngsters who used the automated system had significantly better glycemic control and diabetes self-management skills than those who did not. Now *that's* an mHealth moment worth getting excited about. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/jul2012

Illustration by Leandro Castelao

CONSERVATION

A Home on the Range

After years of legal wrangling, the U.S. government says it will designate critical habitat for the jaguar

Jaguars, the third-largest cats after lions and tigers and the biggest in the Western Hemisphere, used to live here. In the 1700s and 1800s people spotted them in Arizona, New Mexico, California and Texas. Sometimes the cats roamed as far east as North Carolina and as far north as Colorado.

As humans have encroached on their territory, the endangered cats' range has shifted south. Today it stretches from northern Argentina into Mexico's Sonoran Desert. But they cross into the American Southwest frequently enough for some conservationists to argue that they deserve critical habitat protection. Now, after years of legal wrangling, the U.S. Fish and Wildlife Service (FWS) has agreed. "We do plan on proposing to designate some critical habitat," says Steve Spangle, field supervisor for FWS in Phoenix. "But we don't know yet where or how much." The agency plans to announce its decision in July.

The question of whether or not jaguars deserve critical habitat reflects a broader debate in conservation circles. How does one prioritize spending among the many species that are slowly disappearing from the planet? Many experts believe the best way to help the species is to increase resources south of the border, where jaguars live and breed. But Michael Robinson of the Center for Biological Diversity, one of the groups that sued FWS to designate critical habitat, says the goal should be to help jaguars repopulate parts of the U.S. where they have gone extinct, especially since dozens were killed under a federal predator-extermination program that continued into the 1960s. It is important to look at a species' historical range and not just at "a snapshot in time," Robinson contends.

Whatever critical habitat the government grants most likely will be small. In April an outline prepared by an advisory group to FWS focused on an area that includes the southeastern corner of Arizona and a tiny slice of New Mexico's southwestern corner, neglecting New Mexico's Gila National Forest and Arizona's Mogollon Rim, which Robinson says are prime jaguar habitat.

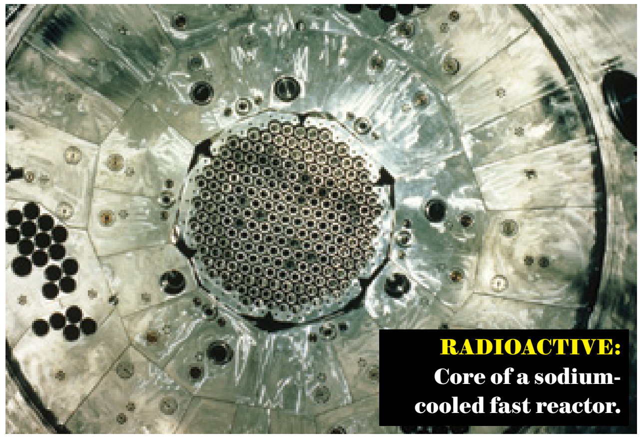
The subject "can be debated for a couple of more generations while the species goes extinct," says Howard Quigley, a co-leader of the advisory group convened by FWS and executive director of the jaguar program at the wild cat conservation group Panthera. "But we need an area in which to focus now and get recovery actions under way." At least it's a start.

—Susan H. Greenberg

ENERGY

Trashing the "Element from Hell"

Experts say we should bury leftover plutonium



RADIOACTIVE: Core of a sodium-cooled fast reactor.

The vast majority of the radioactive plutonium on the planet is man-made—roughly 500 metric tons, or enough to make 100,000 nuclear weapons. Much of it is the legacy of the nuclear arms race between the U.S. and the former Soviet Union. More and more, it is also the legacy of nuclear power.

Now a team of scientists is arguing that burying plutonium is the only reasonable solution to this problematic stockpile. In a comment published in *Nature* in May, a group of physicists and environmental scientists recommends that the U.K. should lead the way by studying how to immobilize the "element from hell" in ceramic pucks that can be buried in deep caverns or boreholes. (*Scientific American* is part of Nature Publishing Group.)

So far countries have been pursuing other options. The U.K. appears to be leaning toward following the example of France and Japan in their attempts to use the plutonium in so-called mixed-oxide, or MOX, nuclear fuel, which combines oxides of uranium and plutonium. The U.S. is doing the same, spending $13 billion to turn 34 metric tons of its plutonium stockpile into MOX at a facility in South Carolina, even though it is more expensive and harder to handle than conventional fuel.

Japan, France, Russia and the U.S. have also used plutonium as fuel in so-called fast reactors, which employ neutrons to initiate fission. The problem is that these high-speed reactors require highly flammable liquid sodium, instead of water, to cool them. And there would still be radioactive material left over, thereby only delaying the problem.

So why not take the cheaper route and immobilize plutonium, then put it deep underground? That may be because finding a place to bury it has proved politically radioactive. Yucca Mountain in Nevada is no closer to being a solution for nuclear waste than in the 1980s, when it was first designated as a final resting place for radioactive residue. Nor has the U.S. adequately prepared financially for tearing down old nuclear reactors and dealing with the radioactive waste left behind, according to an April report from the Government Accountability Office.

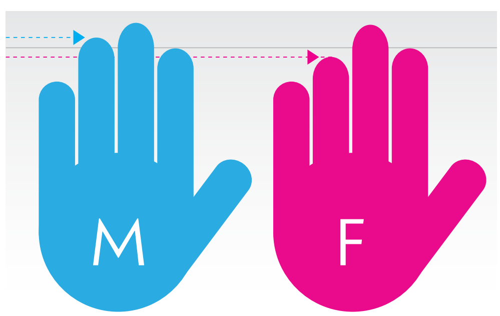
The problem with treating plutonium "unambiguously as the dangerous weapons material that it is," as the scientists put it, is that few want to pay to have it buried, even very deeply, anywhere near their backyard. —*David Biello*

FACT FINDER Information bits from the news

DIGIT DIVIDE

In men the index finger is usually shorter than the ring finger, but in most women it's the other way around, although in some women the fingers are of equal length. In mice the digit ratio corresponds to the female-male hormonal balance in the womb during the week digits form; androgen apparently produces a longer ring finger.

Researchers study these ratios to see if they can serve as markers for certain human attributes. So far in 2012, studies have found that girls with a masculine ratio do not get lost as easily; that a feminine ratio in heterosexual girls is associated with bulimia; and that boys with more masculine ratios have more typically masculine facial features. —*Rebecca Coffey*



VINCENT J. MUSI *National Geographic Stock* (jaguar); PHOTO RESEARCHERS, INC. (reactor)

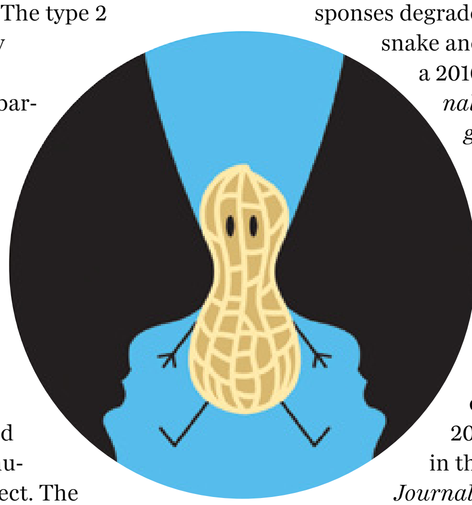
IMMUNOLOGY

Why Sneezing Is Good for You

Allergies may have emerged to protect us from environmental toxins

Most experts consider allergies to be misdirected immune reactions to innocuous substances such as pollen or peanuts. A handful of researchers, however, now propose a fundamentally different theory of allergies: that runny noses, coughs and itchy rashes may have evolved to protect us from toxic chemicals, like snake venom, in our environment and in the food we eat.

Immunologists have long thought that allergy sufferers are the victims of a misdirected type 2 response, which is believed to have evolved to protect against parasites. The type 2 response works by strengthening the body's protective barriers and promoting pest expulsion.



The other way our bodies fight harmful substances is through the type 1 response, which directly kills pathogens such as viruses and bacteria and the human cells they infect. The idea is that smaller pathogens, like viruses, can be killed but that it is smarter to fight larger ones, like parasites, defensively.

But Ruslan Medzhitov, an immunobiologist at Yale University, has never accepted the idea of allergies as rogue soldiers from the body's parasite-fighting army. Parasites and the substances that trigger allergies, called allergens, "share nothing in common," he says. First, there are an almost unlimited number of allergens. Second, allergic responses can be extremely fast—on the scale of seconds—and "a response to parasites doesn't have to be that fast."

In a paper published in April in *Nature,* Medzhitov and his colleagues argue that allergies came about to protect us from potentially toxic substances in the environment or in food. In other words, they have evolved for a reason and aren't just a misdirection. "How do you defend against something you inhale that you don't want? You make mucus. You make a runny nose, you sneeze, you cough. Or if it's on your skin, by inducing itching, you avoid it or you try to remove it by scratching it," he explains. Likewise, if you ingest something allergenic, your body might react with vomiting.

Among the evidence Medzhitov cites is a 2006 study in *Science* that reported that key cells involved in allergic responses degrade and detoxify snake and bee venom. And a 2010 study in the *Journal of Clinical Investigation* suggests that allergic responses to tick saliva prevent the pests from attaching and feeding.

How does this jibe with the prevailing wisdom on allergies? A 2011 study published in the *New England Journal of Medicine* reported that children who grow up on farms, where they are exposed to many microorganisms, are less likely than other kids to develop asthma and allergies. This idea, known as the hygiene hypothesis, suggests that individuals who encounter a multitude of bacteria and viruses early in life invest more immune resources into type 1 responses at the cost of type 2 reactions. Medzhitov maintains that this theory can coexist with his own.

Ultimately Medzhitov's theory raises more questions than it answers, but many agree that the tenets are plausible. "It stimulates us as scientists to draw up some new hypotheses," says Kari Nadeau, an immunologist at the Stanford University School of Medicine.

—Melinda Wenner Moyer

Illustrations by Thomas Fuchs

DO THE MATH

Who's #1?

Why rankings are flawed

Decisions concerning the products we buy, the Web sites we click on, the movies we watch and even where we send our children to college are all affected by rankings. But did you ever wonder who or what is making all these rating decisions? Are they subjective opinions, or is something else going on under the covers?

Put yourself in Mark Zuckerberg's place when he rated and ranked the women of Harvard University for his Facemash site that evolved into Facebook. The most straightforward method would be to ask people to vote for their favorite; a coed's rating would simply be the number of votes received. But this doesn't work well, because rarely are all votes equal. For example, an uninformed vote is usually not as valuable as one from a knowledgeable person, or, in the case of Facemash, a voter's gender might matter.

But assigning weights to voters is often not feasible, especially when voters' identities are unknown, so you might try the Bowl Championship Series approach used to rate college football teams. Applied to a top-10 list of coeds, it would work in this way: Ask voters to assign a score of 10 to their favorite, 9 to their second favorite, and so on. Add up the scores for each woman to arrive at a rating.

Most football fans, however, prefer that their sports teams be ranked according to how well they fare in head-to-head competition. In fact, the pressure from fans has become so great that college football commissioners announced in April that they are contemplating play-off games for the 2014 season. Zuckerberg instinctively knew that implementing head-to-head matchups is a better way to establish ratings. He implemented pair-wise comparisons by displaying a pair of photographs and asking, "Which is hotter?" Scoring is easy. Each matchup is scored by allotting one point to the winner and zero to the loser (each gets half of a point in case of a tie).

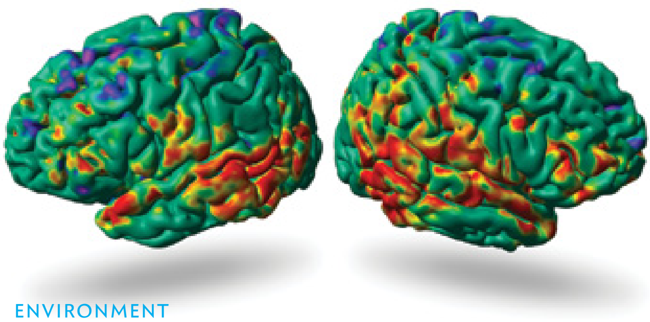
But how does this get turned into ratings? Arpad Elo, a Hungarian-born physicist and avid chess player, theorized that a reasonable approach would be to establish a mean performance level for each player as competition ensues. Once ratings are assigned, they should be changed only in proportion to the degree to which a player performs above or below his or her mean. Elo's idea was later refined by replacing each player's overall mean performance by a relative measure that reflects the expected performance when one player is matched specifically against another player. The logic is that the difference between two players' ratings before they meet should suggest what to expect when they are matched against each other.

Elo's elegant idea has become ubiquitous throughout the gaming world, as well as in soccer and American football. But in each case, the scheme is tweaked to suit the specifics of the competition. We still cannot say that it is the best way to rate and rank things—because there is no best way. In 1951 Kenneth Arrow, a mathematical economist, proved that there can be no optimal ranking system that also satisfies certain fairness criteria. Thus, the controversy lives on, keeping raters and rankers in business by continually tweaking and tailoring their systems to fit specialized needs.

—*Amy N. Langville and Carl D. Meyer*

Langville, a professor of mathematics at the College of Charleston, and Meyer, a professor of mathematics at North Carolina State University, wrote Who's #1?: The Science of Rating and Ranking *(Princeton University Press, 2012).*

TONY CORDOZA *Getty Images*



RED FLAGS: **The brain regions shown in red were enlarged in kids exposed to higher levels of chlorpyrifos in the womb.**

ENVIRONMENT

Bad for Bugs and Brains?

A common pesticide may interfere with a child's brain development

The common pesticide chlorpyrifos has been banned for indoor use since 2000, but its effects can still be found in the brains of young children now approaching puberty. A recent study used magnetic resonance imaging to reveal that children exposed to chlorpyrifos in the womb had changes in the brain that persisted throughout childhood.

Researchers examined the brain scans of 20 children exposed to higher levels of chlorpyrifos in their mother's blood (as measured by serum from the umbilical cord) and found that they looked markedly different compared with those of children exposed to lower levels of the chemical, says epidemiologist Virginia Rauh of the Mailman School of Public Health at Columbia University. Rauh led the research, which was published online in late April in the *Proceedings of the National Academy of Sciences USA*. "During brain development, some type of disturbance took place," she notes.

The six young boys and 14 little girls, whose mothers were exposed to chlorpyrifos when it was commonly used indoors in bug spray before the ban, ranged in age from seven to nearly 10. All came from Dominican or African-American families in the New York City region. Compared with 20 children from the same kinds of New York families who had relatively low levels of chlorpyrifos in umbilical cord blood, the 20 higher-dose kids had protuberances in some regions of the cerebral cortex and thinning in other regions.

Although the study did not map specific disorders tied to any of these brain changes, the regions affected are associated with functions such as attention, decision making, language, impulse control and working memory. The findings echo similar results from animal studies of the insecticide, which remains widely used in agriculture to kill crop-spoiling insects. The good news is that washing fruits and vegetables can rinse away lingering chlorpyrifos and mitigate much of the risk. *—David Biello*

SCIENTIST IN THE FIELD

It's Electric

An M.I.T. Media Lab professor talks about new wristbands that measure seizures

How did this project start?
We built our first sweatband sensor to get emotional information from autistic children outside the lab. But then one of my undergrad researchers asked if he could borrow a wristband for his little brother who had autism. When he came back, we looked at the data and saw this weird peak on one side of [the boy's] body. It turned out that was 20 minutes before his little brother had a seizure.

How do they work?
These bands put a tiny current through the surface of the skin at the sweatband and measure changes in that electric current. The changes show how the brain is reacting to things in a much more detailed way than, say, a heart rate monitor. Sometimes someone's brain might be reacting, but the person doesn't get sweaty or have a higher heart rate. But he or she will have increased conductance. The bands are also easier to wear than the standard EEG [electroencephalogram] cap, which has lots of electrodes.

How can parents use these sweatbands?
Right now we cannot predict seizures. We also don't know why some seizures cause death and others don't. One hypothesis is that after a deadly seizure is over, the brain shuts itself down for too long. If I had a child with epilepsy, I would want to know: Is this a big surge or a little surge? It's hard to tell that just by looking. If the surge was big and the brain shut down, then I'd want to get my kid to a doctor.

How can doctors use the bands?
Before, there was no way to get lots of seizure data unless people were willing to wear an EEG all the time. The wristband could give us that information, and then we could try interventions. *—Rose Eveleth*

PROFILE

NAME
Rosalind Picard

TITLE
Director of affective computing research, M.I.T. Media Lab

LOCATION
Cambridge, Mass.

COURTESY OF BRAD PETERSON *Columbia University and New York State Psychiatric Institute (brains)*; COURTESY OF M. SCOTT BRAUER *(wristband)*

COMMENT AT ScientificAmerican.com/jul2012

HEALTH

Some Like It Too Hot

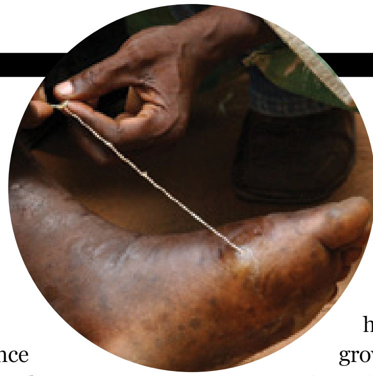
Extramarital sex ups the risk of sudden death

Physicians have known for a long time that, for most men, sex is safe and even life-prolonging. Yet evidence is growing that, at least for adulterers, the picture is different. In a review of the literature on infidelity published online in April in the *Journal of Sexual Medicine,* researchers presented intriguing evidence that extramarital sex can kill.

To be sure, death by copulation is rare. But the data suggest that when it happens, it usually happens to adulterers, and the cause is typically cardiovascular. In 1963 a Japanese pathologist reported that of 34 men who had died during intercourse, nearly 80 percent had died during extramarital sex, most of cardiac causes. In 2006 South Korean pathologists documented 14 cases of sudden coital death and found that only one had involved a man who had been having intercourse with a woman known to be his wife; all the other men had died of cardiovascular causes. In 2006 researchers at Goethe University Frankfurt in Germany published an analysis of sex-related autopsy reports for 68 men. Ten had died with a mistress and 39 with a prostitute.

Why do unfaithful men, especially, die doing what they love to do? "Extramarital sex may have its own hazards," says Alessandra Fisher, the study's lead author and an expert on sexual disorders at the University of Florence. "The lover might be much younger. Sex might be particularly athletic or follow excessive drinking or eating."

Guilt may also play a role. The University of Florence team's 2011 statistical analysis of health outcomes for almost 1,700 male patients showed that those involved in stable extramarital relationships had about twice the cardiovascular disease as other patients in the study, particularly if the man reported that his wife was still sexually interested in him. "Deceiving a sexually available and involved mate could lead to a deeper sense of guilt," the researchers wrote. That type of psychological distress has been shown to up cardiovascular risk. —*Rebecca Coffey*



GLOBAL HEALTH

The Last Worm

A dreaded tropical disease is on the verge of eradication

A parasite that has plagued the human race since antiquity is poised to become the second human disease after smallpox to be eradicated. "We are approaching the demise of the last guinea worm who will ever live on earth," says former U.S. president Jimmy Carter, whose Carter Center has spearheaded the eradication effort.

Unlike polio's high-profile eradication program, the mission to eliminate guinea worm disease has largely been off the public's radar. Affecting some of the poorest and most remote communities in Africa—97 percent of cases are in South Sudan—guinea worm is a parasitic infection caused by the nematode roundworm *Dracunculus medinensis*. It is the only disease transmitted solely by drinking water, and humans are its only reservoir, says James Hughes, professor of medicine and public health at Emory University. The disease spreads when villagers consume water containing fleas that harbor guinea worm larvae. The larvae grow to maturity inside the human body and emerge after a year as a fully grown two- to three-foot-long worm that often exits through the leg or foot. It is an excruciatingly painful process, and individuals often immerse the limb in water to cool the burning sensation, which starts the cycle all over again.

Since 1986 groups such as the Carter Center have distributed cloth water filters to villagers and educated residents about how not to spread the infection. They have also selectively used Abate, a larvicide, to control fleas in the drinking water.

So far the efforts have resulted in a 99 percent reduction in infections, says Sharon Roy of the U.S. Centers for Disease Control and Prevention. In 1986 there were 3.5 million cases, as compared with only 1,060 in 2011 and a mere five as of the first few months of 2012. *—Roxanne Nelson*

WHAT IS IT?

Crowded sea life: Even after the ocean recedes, water remains in the coastline's crevices to form tide pools teeming with marine life. Photographer Ted Morrison captured the flora and fauna living along the 40-mile-plus rocky shoreline of Maine's Acadia National Park. In this close-up view of a small tide pool, Morrison found the flourishing barnacle species *Semibalanus balanoides* (*yellow*), along with dark specks of blue mussel called *Mytilus edulis* and a *Fucus* rockweed species peeking out from the center of the water. These are the three most common marine organisms found on the New England shores, says University of Maine marine sciences professor Susan Brawley. The best times to uncover these small environments are during the low tides of the spring's full and new moons. *—Ann Chin*

VANESSA VICK *Redux Pictures* (*worm*); TED MORRISON (*tide pool*)

COMMENT AT ScientificAmerican.com/jul2012

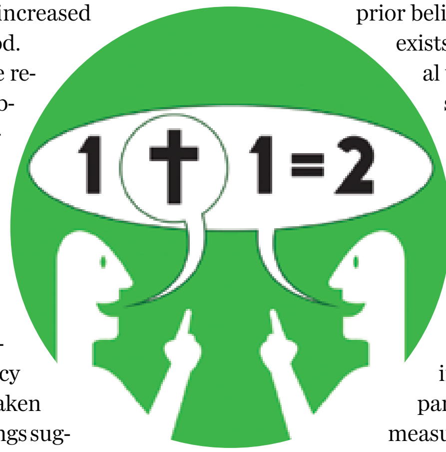
PSYCHOLOGY

How Critical Thinkers Lose Their Faith in God

Faith and intuition are intimately related

Why are some people more religious than others? Answers to this question often focus on the role of culture or upbringing. Although these influences are important, new research suggests that whether we believe or not may also have to do with how much we rely on intuition versus analytic thinking. In 2011 researchers from Harvard University published a paper showing that people who have a tendency to rely on their intuition are more likely to believe in God. They also showed that encouraging people to think intuitively increased people's belief in God.

Building on these results in an article published in *Science* recently, Will Gervais and Ara Norenzayan of the University of British Columbia found that encouraging people to think analytically reduced their tendency to believe in God. Taken together, these findings suggest belief may stem at least in part from our thinking styles.



Gervais and Norenzayan's research is based on the idea that we possess two different ways of thinking that are related. Understanding these two ways, which are often referred to as system 1 and system 2, may be important for understanding our tendency toward having religious faith. System 1 thinking relies on shortcuts and rules of thumb, whereas system 2 relies on analytic thinking and tends to be slower and to require more effort. Solving logical and analytic problems may require that we override our system 1 thinking processes to engage system 2. Psychologists have developed a number of clever techniques that spur us to do this. Using some of these techniques, Gervais and Norenzayan examined whether engaging system 2 leads people away from believing in God and religion.

In one activity, Gervais and Norenzayan gave participants sets of five randomly arranged words (such as "high winds the flies plane") and asked them to drop one word and rearrange the others to construct a more meaningful sentence (such as "the plane flies high"). Those participants who unscrambled sentences that contained words related to analytical thinking (such as "reason" or "ponder") were less likely to express agreement with the statement that God exists. People's prior belief in whether God exists, as measured several weeks before the study took place, was found to be unrelated to the results.

In another experiment, the investigators used an even more subtle way of activating analytic thinking: by having participants fill out a survey measuring their religious beliefs that was printed either in a clear font or in one that was difficult to read. Prior research has shown that a difficult-to-read font promotes analytic thinking by forcing volunteers to slow down and deliberate more carefully about the meaning of what they are reading. The researchers found that participants who completed a survey that was printed in an unclear font expressed less belief as compared with those who filled out the same survey in the clear font.

These studies demonstrate yet another way in which our thinking tendencies, many of which may be innate, have contributed to religious faith. It may also help explain why the vast majority of Americans tend to believe in God. Because system 2 thinking requires effort, most of us tend to rely on our system 1 thinking processes whenever possible. *—Daisy Grewal*

COMMENT AT ScientificAmerican.com/jul2012

CONSERVATION

Tracking Turtles from Space

A satellite study pinpoints where leatherbacks and fishing trawlers cross paths

HATCHLING leatherback turtle

MIKE PARRY *Minden Pictures*

At 2,000 pounds and six and a half feet in length, leatherback turtles are the largest living reptiles. Their size, however, belies their fragility: among the leatherbacks that live in the Pacific Ocean, populations have dropped by 90 percent in the past 20 years. Biologists already knew that fishing gear posed a problem for the endangered turtles, which can get entangled in trawlers' nets, but they were not sure exactly where and when they were running into trouble.

"These animals travel thousands of miles across the Pacific, so there's no way we can track them from land or boat," says marine biologist Helen Bailey of the University of Maryland Center for Environmental Science. So Bailey and her colleagues set out to follow them by satellite. The scientists positioned harnesses with tracking devices on the leatherbacks' soft shells; the devices transmitted a signal each time the turtles surfaced. The study, published in the April issue of *Ecological Applications,* pinpoints danger zones where turtles and trawlers meet. These data will help regulatory agencies decide the times and places they might limit fishing to protect the species.

The researchers followed 135 females, some from the eastern Pacific and some from the western Pacific, over 15 years as they crisscrossed the ocean hunting for jellyfish. The study found that the migration patterns for the two Pacific populations were different. Western Pacific leatherbacks leave Indonesian nesting sites to feed in the South China Sea, Indonesian seas and southeastern Australia and along the U.S. West Coast, making them vulnerable to fishing nets in many different areas.

The eastern Pacific leatherbacks traveled from nesting sites in Mexico and Costa Rica to the southeastern Pacific, with many getting snagged in fishing gear along the coast of South America. Because the eastern population is more concentrated in range, its risk of extinction is greater, Bailey says.

The new findings could help decision makers plan short-term fishery closures. Bailey credits a recent decision to close a swordfish and thresher shark fishery in California from mid-August to mid-November each year with dramatically reducing leatherback bycatches. (In 2010 no turtles were caught.) The satellite tracks can help refine the time and area of this closure and guide closures off the coast of Oregon and Washington. In the Galápagos Islands, leatherbacks go through a very specific migration corridor from February to April, so a timely closure in that area could reduce bycatch by 100 percent.

"We had some inkling that fisheries were the problem," Bailey says, "but now we know where to target our efforts."

—Carrie Madren

Best of the Blogs

PHYSICS

Particles for Peace

Iranian, Israeli, Turkish and Arab physicists plan a joint accelerator

Physics has always been one of the most globalized of professions. Physicists think of themselves as supranational, rising above national and cultural concerns. They may not always live up to this ideal, but at least they try. I got a glimpse of this as a college student in 1987, when I spent my spring break at Bell Labs. High-temperature superconductors had just been discovered, and I had some fun levitating magnets (and collaborated on a published paper). Over lunch, the talk turned to poking holes in the iron curtain. Lab scientists were making contacts with colleagues in the Soviet Union, organizing joint conferences and translating articles from or into Russian. They told me stories about Andrei Sakharov and the Pugwash conferences, which brought together scholars from all countries to work toward nuclear disarmament and later won a Nobel Peace Prize.

This idealistic urge remains powerful. In April, at a workshop I was attending on black holes, I talked to Eliezer Rabinovici, a theoretical physicist at the Hebrew University in Jerusalem. He and his colleagues may well be the only people on the planet to have gotten Arabs, Iranians, Turks and Israelis to agree on anything. Many countries around the Middle East have signed on to their project to build a particle accelerator for joint use: SESAME.

The decades-long effort has made understanding the nature of space, time and matter look trivial. "I had a vision to try and work with our neighbors, to do something for our common humanity," Rabinovici says. "That sounds bombastic, but that's what SESAME is all about."

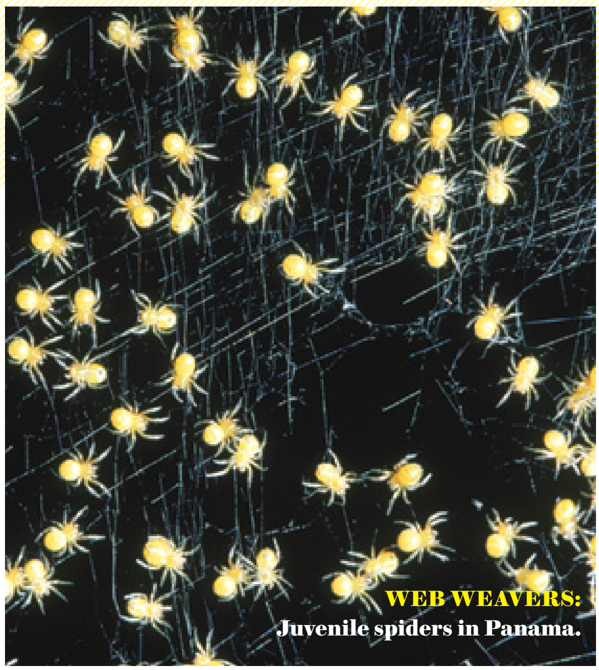
The project has managed to hang together despite the tumult of the past two decades. It chose a laboratory site in Jordan in 2000, completed the building in 2008 and settled on the synchrotron design. It is not really a particle physics project but a general source of radiation for chemistry, biology, pharmaceutical development and other fields—a diversity that is matched to the region's needs.

In March, Iran, Turkey, Jordan and Israel pledged $20 million for the main accelerator. The project has now gone, cap in hand, to the U.S. and the European Union for the balance, about $15 million.

In 1954 European scientists founded CERN near Geneva so that German, French, British and other ex-adversaries would have a place to shoot particles rather than bullets. "It was one of the places where Europe was reborn," Rabinovici says. SESAME arguably has the tougher task because the adversaries are not yet "ex." Another Israeli theorist, Ramy Brustein, compares it to "climbing on an ice wall." Yet in 1987 everyone thought the same of cultural exchanges across the Berlin Wall.

—George Musser

Adapted from Observations at blogs.ScientificAmerican.com/observations



WEB WEAVERS: Juvenile spiders in Panama.

GARY RETHERFORD *Photo Researchers, Inc.*

ENTOMOLOGY

How Spiders "Balloon"

The science behind a scene in *Charlotte's Web*

Charlotte's Web, the E. B. White childhood classic, ends with Wilbur the pig eagerly waiting for Charlotte's baby spiders to emerge from their egg sac in spring. When they finally crawl out, they do something that seems pretty amazing to anyone not familiar with how some spiders travel long distances: they fly away. "One spider climbed to the top of the fence," White wrote. "Then it did something that came as a great surprise to Wilbur. The spider stood on its head, pointed its spinnerets in the air, and let loose a cloud of fine silk. The silk formed a balloon. As Wilbur watched, the spider let go of the fence and rose into the air.... 'Wait a minute!' screamed Wilbur. 'Where do you think you're going?' But the spider was already out of sight."

Charlotte's hatchlings were "ballooning," which is the method that some spiders, especially baby spiders, use to disperse themselves through nature. Richard Bradley, an entomologist at Ohio State University, says that the phenomenon happens all over the country in spring, summer and fall but that it is tricky to catch. "The key is weather," he wrote in an e-mail. "You need a relatively calm air or a slight breeze—ballooning doesn't happen often in wind. The rising air currents created by the sun heating the ground are the launching force for these tiny flights." Bradley recommends going to "exposed places with prominent launchpads," such as fence posts, stumps, small bushes or even an unmown lawn on a cool, clear morning, and looking for silk lines or lots of webbing. "If you find this, you might be in for a treat," he says. *—Anna Kuchment*

Adapted from Budding Scientist at blogs.ScientificAmerican.com/budding-scientist

COMMENT AT ScientificAmerican.com/jul2012

Ariel Bleicher is a science writer and an associate editor at *IEEE Spectrum*. She has written for *Discover, Popular Mechanics* and *Scientific American Mind.*

Perils of Newborn Screening

Doctors may be testing infants for too many diseases

The first symptoms often appear a month or two after birth. The babies' muscles stiffen. They lose their hearing and vision, stop sleeping and scream in pain. Some develop seizures. By the time many parents learn that their children have Krabbe disease—a rare genetic disorder that degrades nerve cells—it is too late for the only viable treatment, a transfusion of umbilical cord blood stem cells from healthy donors. Children with full-blown Krabbe who do not receive medical treatment, as well as many who do get treated, usually die by age two.

In some cases, doctors can prevent this grim outcome by screening infants at birth for genetic harbingers of disease. Right now such tests are mandatory in only a few states—something that many parents want to change. "If we don't screen for this disease at birth, those children will never have a chance at life," says Jacque Waggoner, CEO of Hunter's Hope Foundation, one of several advocacy groups lobbying state politicians to add mandatory tests for Krabbe and other rare diseases. The politicians are starting to listen. In the past year four states have passed legislation that requires hospitals to check newborns for abnormal enzyme levels linked to as many as seven new diseases.

Within the medical community, however, doctors are debating the rapid expansion of screening programs. As a whole, the programs have saved many lives. But some experts worry that states may be aggressively demanding tests for diseases that do not always develop in those who show signs of risk or cannot be safely or effectively treated even when they are caught. Doctors who have recently started screening for Krabbe and similar rare diseases are swiftly realizing that, in many cases, the results of such mandatory tests unnecessarily frighten parents and fail to help the children the tests were designed to save.

THE BIRTH OF NEWBORN SCREENING

THE CURRENT DEBATE has origins in the earliest forms of newborn screening. By the early 1960s microbiologist Robert Guthrie had perfected a test for phenylketonuria (PKU) that simply required a drop of blood from a baby's heel. Children with PKU suffer brain damage and seizures because they cannot break down the amino acid phenylalanine, which is found in high-protein foods.

Although most states adopted the procedure, a few doctors worried that some babies who did not have PKU would test positive and suffer malnourishment as a consequence of a low-protein diet. Ultimately the doctors' fears proved unfounded. (In a 2006 review of the medical literature on PKU, Jeffrey Brosco and his colleagues at the University of Miami found "no published cases of children who suffered permanent harm after an erroneous [newborn screening] test and treatment for a condition they did not have.") States soon began using similar tests to screen for the likelihood of developing other easily treatable diseases, including congenital hypothyroidism and sickle cell disease.

HARD TO HEAL: Screening infants' blood for signs of disease may not make sense if effective treatment does not exist.

J. SCOTT APPLEWHITE *AP Photo*

Today all states require newborn screening for between 28 and 57 medical disorders. Overall, these mandatory programs mark "one of the most significant advances ever in public health," says Stuart Shapira, a medical geneticist at the Centers for Disease Control and Prevention. Of the four million babies born in the U.S. every year, newborn screening identifies 12,500 with medical disorders. Catching and treating many of these disorders early, Shapira says, can prevent intellectual and developmental disabilities, organ damage and death.

Recently, however, doctors have raised new concerns, this time about the repercussions of widespread newborn screening. By the 1990s a tool known as tandem mass spectrometry had drastically expanded the number of disorders laboratory technicians could detect with a single drop of blood—from one to as many as 20. A mass spectrometer sorts and counts variously sized molecules in the blood, somewhat like a change machine sorts coins. Unusually high levels of certain molecules indicate the enzymes that normally break down these molecules are missing or deficient, which in turn suggests a genetic disorder.

Before 1995 no U.S. state had screened babies for more than eight disorders. A decade later some states were screening for anywhere from seven to 52. States lacked clear consensus on which disorders warranted mandatory screening, says Michael Watson, executive director of the American College of Medical Genetics and Genomics. To remedy the situation, the Health Resources and Services Administration commissioned Watson to review the scientific literature on 84 disorders and to determine which of the screens clearly benefited newborns.

In a report made in 2005 Watson recommended that all states screen for 29 disorders that doctors could clearly predict and treat. He further advised against screening for Krabbe and other diseases because there was not enough evidence that early intervention did more good than harm. Most states currently screen for all 29 recommended disorders, but some, like New York, also test for Krabbe or other conditions outside the uniform panel—including Pompe (a muscle-weakening disease) and Fabry (a metabolic disease causing severe pain). The outcomes of New York's decision to screen for Krabbe underscore why some doctors believe that enthusiasm for screening has gone too far.

When Should Doctors Screen?

According to guidelines proposed by the World Health Organization in 1968, doctors should screen for a medical condition only if:

- ✔ **The condition is an important health problem.**
- ✔ **Doctors can effectively treat the condition.**
- ✔ **Patients have access to diagnostic services and treatment.**
- ✔ **Doctors can recognize a latent stage and early symptoms.**
- ✔ **Doctors have devised an accurate test for the condition.**
- ✔ **The general population understands the rationale behind such tests.**
- ✔ **Doctors understand how the disease develops.**
- ✔ **Doctors agree on which patients should be treated.**
- ✔ **Screening is affordable.**
- ✔ **Doctors plan to continue screening new generations of children.**

PREMATURE ENTHUSIASM

SINCE ITS INCEPTION in 2006 New York's program has tested one million babies and identified more than 200 infants with unusually low levels of some enzymes, indicating risk for Krabbe. Lab technicians verify these results with both enzyme and genetic tests. What investigators have found has been surprising.

Of the 228 infants who tested positive for Krabbe, 24 were found to have genetic markers associated with the disease. So far, however, only four of those children have developed Krabbe symptoms, whereas the other 20 continue to appear healthy. In the vast majority of cases, symptoms of Krabbe appear in early infancy and quickly worsen. A few reports in patient registries describe infants who developed symptoms—albeit mild ones—later in life. The 20 New York infants who screened positive for genetic markers of Krabbe but have not yet shown symptoms may have this late-onset form of Krabbe.

But researchers do not understand late-onset Krabbe well enough to know when, if ever, any of these children will develop symptoms. Only when clinicians detect nerve damage in a battery of invasive neurological exams, including brain imaging and a spinal tap, can they be sure that a child has Krabbe. And only then are they certain that treatment justifies its inherent risks. Studies have shown that early stem cell transplants sometimes stop the disease from progressing, although around 30 percent of children do not survive the procedure and all who do still have trouble speaking and moving their limbs.

Many of the 20 children whose tests suggest late-onset Krabbe but who are not yet sick continue to get neurological exams about every four to six months. Some researchers call these children "patients in waiting." As Jennifer Kwon, a neurologist at University of Rochester Medical Center, puts it, "There's this whole group of children nobody expected to find." The problem, Kwon says, is that parents of patients in waiting do not know what to do with the information they receive from doctors or even what to expect. Parents begin to worry excessively, become overprotective, pursue risky tests and procedures, and avoid routine ones. "It's a huge burden for parents to carry around this knowledge that many of them didn't ask for," agrees Melissa Wasserstein, a pediatrician at Mount Sinai Hospital. "Every time their child so much as trips and falls, they're thinking, 'Oh, my God, does this mean the start?'"

Patricia K. Duffner, who directs the research arm of Hunter's Hope at the University of Buffalo, counters that many parents prefer to know about their child's risk because, if symptoms appear, they will not lose time searching for a diagnosis.

Other experts argue that forcing parents to participate in a public health program when the benefits of screening may not outweigh the emotional trauma is unfair. "So far what's come out of the Krabbe program is we've done a lot of screening, we've scared a lot of parents and we haven't truly helped a kid," says Lainie Friedman Ross, an ethicist and pediatrician at the University of Chicago. According to the doctors who cared for the four New York infants with early-onset Krabbe, one family refused a transplant and the baby died; a second baby died from complications of a transplant; and a third child's affliction continues to progress despite a successful transplant. Only one baby has clearly benefited from screening. At three years, though, he is the size of a one-year-old and recently lost his ability to walk.

Ross fears that newborn screening is destined for another rapid, premature expansion as genome-sequencing technologies become inexpensive enough to use routinely. "With these new test platforms, there is the potential to test for hundreds of conditions we don't fully understand," she says. "If adults can refuse these tests, why should we force them on children?"

Jeff Botkin, a medical ethicist at the University of Utah School of Medicine, has similar concerns. "I think people sometimes forget that we're talking about the state mandating these tests. That's a big deal. If we're going to say to parents, 'You don't have a choice,' there ought to be clear justification for doing a test. We shouldn't just add these things because we can." SA

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David Pogue is the personal-technology columnist for the *New York Times* and host of *NOVA scienceNOW,* whose new season premieres in October on PBS.

Technology That Doesn't Fly

Outdated screening rules aren't making for safer skies—just longer lines

The attacks of September 11, 2001, changed everything, especially in air travel. Since that day, the U.S. government has spent billions on technology, enacted rafts of new rules and turned flying into a far more upsetting, complicated procedure than it needs to be.

If it were all based on science and reason, critics might not be calling these new procedures "security theater"—an elaborate show to convince people that the authorities are doing something rather than nothing.

Take the Transportation Security Administration's rules about carry-on electronics, for example. Laptops have to come out of their bags and lie flat in a plastic tub—but not tablets, phones, Kindles, cameras or portable game consoles. Why the distinction?

The TSA says that it's not just about detecting explosives: removing bigger gadgets also unclutters your bag for better x-ray examination. Even so, on close inspection the rules get arbitrary very quickly. For example, according to the TSA, the 11-inch model of the MacBook Air is fine to leave in your bag, but the 13-inch model must be removed.

Then there are the airport checkpoints, where the old metal detectors are being replaced by millimeter-wave and backscatter scanners. They are supposed to be able to find nonmetal weapons and other contraband—not just objects made of metal. Many people consider these machines invasive (they can see through your clothes), overpriced (at least $160,000 apiece) and, in the case of the backscatter machines, a potential cancer risk.

They also require twice as many employees to operate and far more passenger preparation (you can't have anything in your pockets, not even your wallet or boarding pass). And they are much slower—the TSA says screening takes "less than a minute," but that's about 60 times longer than it takes to walk through a metal detector. As a result, some airports now suggest checking in two hours before a domestic flight. How many millions of dollars in productivity are we losing as a result?

With these machines, we trade convenience for security. But look—if we're going to adapt a "security at any cost to convenience" policy, why not prohibit all luggage and require everyone to fly naked?

Finally, there's the Federal Aviation Administration rule that all electronics, even headphones and e-book readers, have to be turned off during takeoff and landing, allegedly to prevent interference with the plane's navigation systems.

But the scientific evidence for this worry is sketchy. Some devices emit signals that could theoretically affect an aircraft's electronics. Yet "there have never been any reported accidents from these kinds of devices on planes," FAA spokesperson Les Dorr told the *New York Times* last year. Once again, irrational fear, not solid science, is dictating policy for millions of travelers.

My field is technology, so I really shouldn't go into the other absurdities of TSA rules. I shouldn't mention how you can't have more than 3.4 ounces of liquid in a container, but you (and the group you are with) can bring lots of those little containers. Or how a full container of liquid is okay if you say that it's baby formula. Or that you have to throw away a seven-ounce toothpaste tube even if it's 80 percent empty. Or how kids who are 12 years old and younger no longer have to remove their shoes.

Or how all of this is focused on preventing a terrorist attack on a plane of 100 people—while far less attention is paid to far more populated targets, such as train stations, theaters, sports arenas and, yes, airports.

The TSA is not completely unaware of its public image, and it's making erratic headway in improving passenger experience. Airport scanners no longer send naked pictures of you to an off-site screener (software does the analysis now). And the TSA pre-check program (currently used by a couple of airlines and 15 airports, with more on the way) gives low-risk travelers a special line, where removing shoes and coats isn't necessary.

Still, on balance, the TSA's irrational half measures and out-of-date electronics policies don't protect us all that well from terrorists. They do, however, make life miserable for the innocent. SA

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Five in-flight apps: ScientificAmerican.com/jul2012/pogue

Illustration by MCKIBILLO

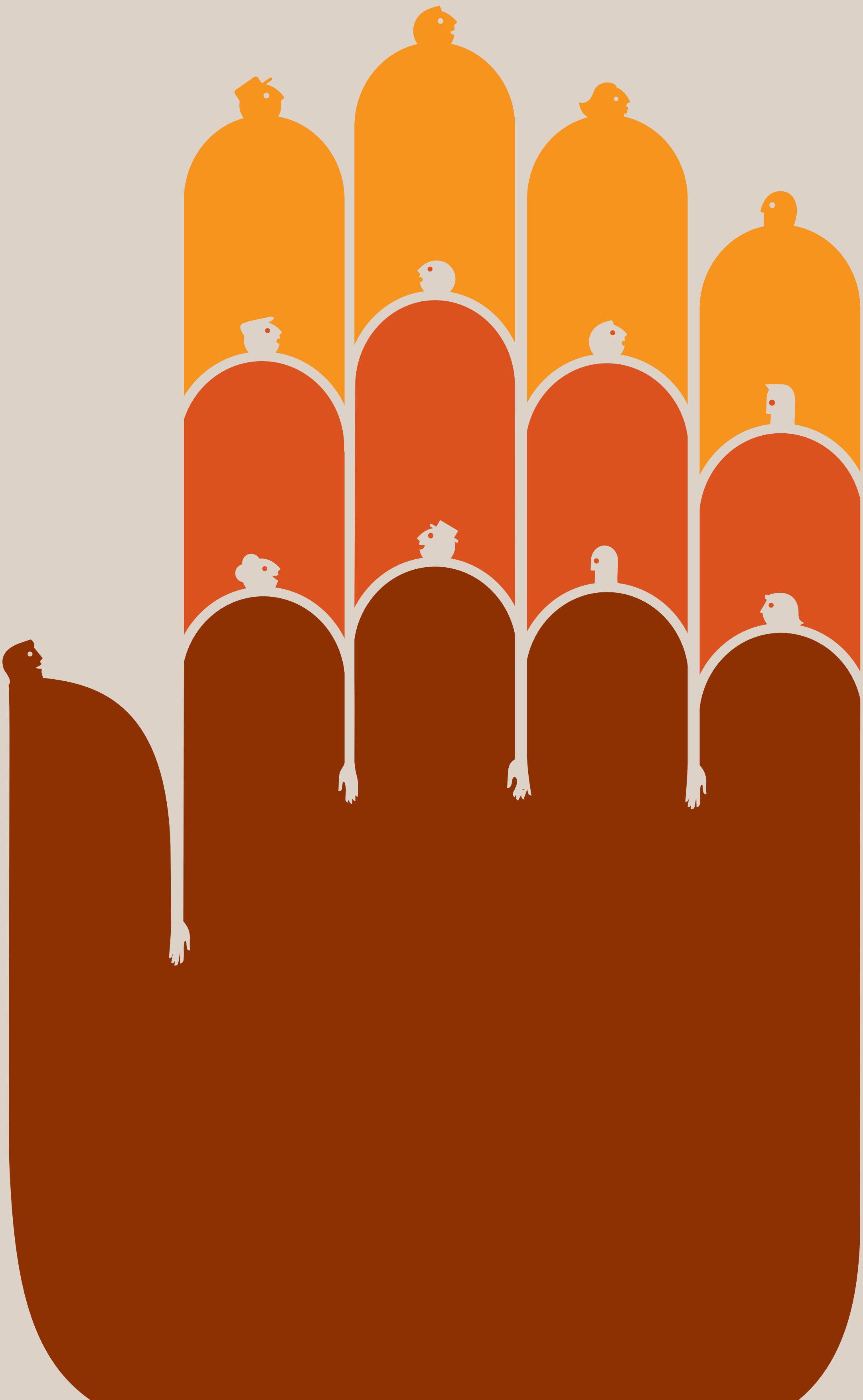
EVOLUTION

WHY WE HELP

Far from being a nagging exception to the rule of evolution, cooperation has been one of its primary architects

By Martin A. Nowak

Illustration by Noma Bar



Martin A. Nowak is a professor of biology and mathematics at Harvard University and director of the Program for Evolutionary Dynamics. His research focuses on the mathematical underpinnings of evolution.

LAST APRIL, AS REACTORS AT JAPAN'S FUKUSHIMA DAIICHI NUCLEAR POWER PLANT WERE MELTING down following a lethal earthquake and tsunami, a maintenance worker in his 20s was among those who volunteered to reenter the plant to try to help bring things back under control. He knew the air was poisoned and expected the choice would keep him from ever marrying or having children for fear of burdening them with health consequences. Yet he still walked back through Fukushima's gates into the plant's radiation-infused air and got to work—for no more compensation than his usual modest wages. "There are only some of us who can do this job," the worker, who wished to remain anonymous, told the *Independent* last July. "I'm single and young, and I feel it's my duty to help settle this problem."

Although they may not always play out on such an epic scale, examples of selfless behavior abound in nature. Cells within an organism coordinate to keep their division in check and avoid causing cancer, worker ants in many species sacrifice their own fecundity to serve their queen and colony, female lions within a pride will suckle one another's young. And humans help other humans to do everything from obtaining food to finding mates to defending territory. Even if the helpers may not necessarily be putting their lives on the line, they are risking lowering their own reproductive success for the benefit of another individual.

For decades biologists have fretted over cooperation, scrambling to make sense of it in light of the dominant view of evolution as "red in tooth and claw," as Alfred, Lord Tennyson so vividly described it. Charles Darwin, in making his case for evolution by natural selection—wherein individuals with desirable traits reproduce more often than their peers and thus contribute more to the next generation—called this competition the "struggle for life most severe." Taken to its logical extreme, the argument quickly leads to the conclusion that one should never ever help a rival and that an individual might in fact do well to lie and cheat to get ahead. Winning the game of life—by hook or by crook—is all that matters.

Why, then, is selfless behavior such a pervasive phenomenon? Over the past two decades I have been using the tools of game theory to study this apparent paradox. My work indicates that instead of opposing competition, cooperation has operated alongside it from the get-go to shape the evolution of life on earth, from the first cells to *Homo sapiens*. Life is therefore not just a struggle for survival—it is also, one might say, a snuggle for survival. And in no case has the evolutionary influence of cooperation been more profoundly felt than in humans. My findings hint at why this should be the case and underscore that just as helping one another was the key to our success in the past, so, too, is it poised to be vital to our future.

FROM ADVERSARY TO ALLY

I FIRST BECAME INTERESTED in cooperation back in 1987, as a graduate student studying mathematics and biology at the University of Vienna. While on a retreat with some fellow students and professors in the Alps, I learned about a game theory paradox called the Prisoner's Dilemma that elegantly illustrates why cooperation has so flummoxed evolutionary biologists. The dilemma goes like this: Imagine that two people have been arrested and are facing jail sentences for having conspired to commit a crime. The prosecutor questions each one privately and lays out the terms of a deal. If one person rats on the other

IN BRIEF

People tend to think of evolution as a strictly dog-eat-dog struggle for survival. In fact, cooperation has been a driving force in evolution.

There are five mechanisms by which cooperation may arise in organisms ranging from bacteria to human beings.

Humans are especially helpful because of the mechanism of indirect reciprocity, which is based on reputation and leads us to help those who help others.

and the other remains silent, the incriminator gets just one year of jail time, whereas the silent person gets slammed with a four-year sentence. If both parties cooperate and do not rat on each other, both get reduced sentences of two years. But if both individuals incriminate each other, they both receive three-year sentences.

Because each convict is consulted separately, neither knows whether his or her partner will defect or cooperate. Plotting the possible outcomes on a payoff matrix [*see box below*], one can see that from an individual's standpoint, the best bet is to defect and incriminate one's partner. Yet because both parties will follow that same line of reasoning and choose defection, both will receive the third-best outcome (three-year sentences) instead of the two-year sentences they could get by cooperating with each other.

The Prisoner's Dilemma seduced me immediately with its power to probe the relation between conflict and cooperation. Eventually my Ph.D. adviser, Karl Sigmund, and I developed techniques to run computer simulations of the dilemma using large communities rather than limiting ourselves to two prisoners. Taking these approaches, we could watch as the strategies of the individuals in these communities evolved from defection to cooperation and back to defection through cycles of growth and decline. Through the simulations, we identified a mechanism that could overcome natural selection's predilection for selfish behavior, leading would-be defectors to instead lend helping hands.

We started with a random distribution of defectors and cooperators, and after each round of the game the winners would go on to produce offspring who would participate in the next round. The offspring mostly followed their parents' strategy, although random mutations could shift their strategy. As the simulation ran, we found that within just a few generations all the individuals in the population were defecting in every round of the game. Then, after some time, a new strategy suddenly emerged: players would start by cooperating and then mirror their opponents' moves, tit for tat. The change quickly led to communities dominated by cooperators.

This mechanism for the evolution of cooperation among individuals who encounter one another repeatedly is known as direct reciprocity. Vampire bats offer a striking example. If a bat misses a chance to feed directly on prey one day, it will beg from its sated peers back at the roost. If it is lucky, one of its roost mates will share its blood meal by regurgitating it into the hungry bat's mouth. The vampires live in stable groups and return to the roost every day after hunting, so group members routinely encounter one another. Studies have shown that the bats remember which bats have helped them in times of need, and when the day comes that the generous bat finds itself in need of food, the bat it helped earlier is likely to return the favor.

What made our early computer simulations even more interesting was the revelation that there are different kinds of direct reciprocity. Within 20 generations the initial tit-for-tat strategy had given way to a more generous strategy in which players might still cooperate even if their rival defected. We had, in essence, witnessed the evolution of forgiveness—a direct-reciprocity strategy that allows players to overlook the occasional mistake.

In addition to direct reciprocity, I later identified four more mechanisms for the evolution of cooperation. In the several thousand papers scientists have published on how cooperators could prevail in evolution, all the scenarios they describe fall into one or more of these five categories.

A second means by which cooperation may find a foothold in a population is if cooperators and defectors are not uniformly distributed in a population—a mechanism termed spatial selection. Neighbors (or friends in a social network) tend to help one another, so in a population with patches of cooperators, these helpful individuals can form clusters that can then grow and thus prevail in competition with defectors. Spatial selection also operates among simpler organisms. Among yeast cells, cooperators make an enzyme used to digest sugar. They do this at a cost to themselves. Defector yeast, meanwhile, mooch off the cooperators' enzymes instead of making their own. Studies conducted by Jeff Gore of the Massachusetts Institute of Technology and, independently, by Andrew Murray of Harvard University have found that among yeast grown in well-mixed populations, the defectors prevailed. In populations with clumps of cooperators and defectors, in contrast, the cooperators won out.

Perhaps one of the most immediately intuitive mechanisms for the evolution of selflessness concerns cooperation among genetically related individuals, or kin selection. In this situation, individuals make sacrifices for their relatives because those relatives share their genes. Thus, although one may be reducing one's own direct reproductive fitness by assisting a relative in need, one is still fostering the spread of those genes the helper shares with recipients. As 20th-century biologist J.B.S. Haldane, who first men-

BASICS

Natural Defection

A game theory paradox called the Prisoner's Dilemma illustrates why the existence of cooperation in nature is unexpected. Two people face jail sentences for conspiring to commit a crime. Their sentences depend on whether they elect to cooperate and remain silent or defect and confess to the crime [*see payoff table below*]. Because neither knows what the other will do, the rational choice—the one that always offers the better payoff—is to defect.

INDIVIDUAL 1 \ INDIVIDUAL 2	COOPERATE (remain silent)	DEFECT (confess)
COOPERATE (remain silent)	2 years in jail 2 years in jail	4 years in jail 1 year in jail
DEFECT (confess)	1 year in jail 4 years in jail	3 years in jail 3 years in jail

tioned the idea of kin selection, put it: "I will jump into the river to save two brothers or eight cousins," referring to the fact that our siblings share 50 percent of our DNA, whereas our first cousins share 12.5 percent. (It turns out that calculating the fitness effects of kin selection is a rather complicated task that has misled many researchers. My colleagues and I are now engaged in an intense debate about the underlying mathematics of kin selection theory.)

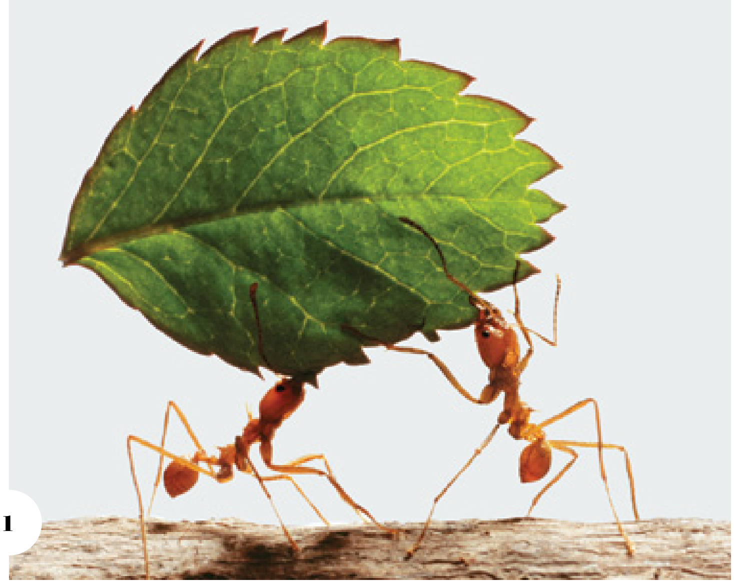
The fourth mechanism that fosters the emergence of cooperation is indirect reciprocity, which is quite distinct from the direct variety that Sigmund and I studied initially. In indirect reciprocity, one individual decides to aid another based on the needy individual's reputation. Those who have a reputation for assisting others who fall on hard times might even find themselves on the receiving end of goodwill from strangers when their own luck takes a turn for the worse. Thus, instead of the "I'll scratch your back if you scratch my mine" mentality, the cooperator in this situation might be thinking, "I'll scratch your back, and someone will scratch mine." Among Japanese macaques, for example, low-ranking monkeys that groom high-ranking ones (which have good reputations) may better their own reputations—and hence receive more grooming—simply by being seen with the top brass.

Last, individuals may perform selfless acts for the greater good, as opposed to abetting a single peer. This fifth means by which cooperation may take root is known as group selection. Recognition of this mechanism dates back to Darwin himself, who observed in his 1871 book *The Descent of Man* that "a tribe including many members who … were always ready to aid one another, and to sacrifice themselves for the common good, would be victorious over most other tribes; and this would be natural selection." Biologists have since argued fiercely over this idea that natural selection can favor cooperation to improve the reproductive potential of the group. Mathematical modeling by researchers, including me, however, has helped show that selection can operate at multiple levels, from individual genes to groups of related individuals to entire species. Thus, the employees of a company compete with one another to move up the corporate ladder, but they also cooperate to ensure that the business succeeds in its competition with other companies.

ONE FOR ALL

THE FIVE MECHANISMS governing the emergence of cooperation apply to all manner of organisms, from amoebas to zebras (and even, in some cases, to genes and other components of cells). This universality suggests that cooperation has been a driving force in the evolution of life on earth from the beginning. Moreover, there is one group in which the effects of cooperation have proved especially profound: humans. Millions of years of evolution transformed a slow, defenseless ape into the most influential creature on the planet, a species capable of inventing a mind-boggling array of technologies that have allowed our kind to plumb the depths of the ocean, explore outer space and broadcast our achievements to the world in an instant. We have accomplished these monumental feats by working together. Indeed, humans are the most cooperative species—supercooperators, if you will.

Given that the five mechanisms of cooperation occur throughout nature, the question is: What makes humans, in particular, the most helpful of all? As I see it, humans, more than any other creature, offer assistance based on indirect reciprocity, or reputation.



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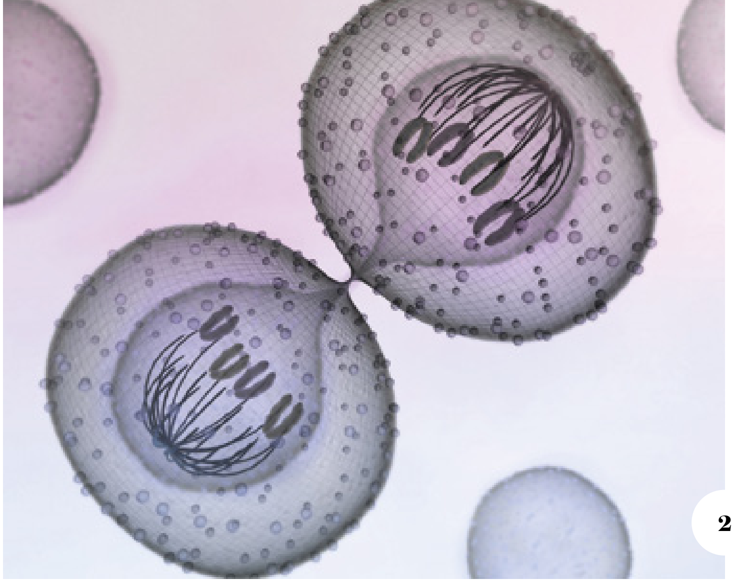
HELPING OUT: Leaf-cutter ants work together to carry foliage back to their nest (*1*). Cells regulate their own division to avoid causing cancer (*2*). Lionesses cooperatively rear their young (*3*). Japanese macaques groom each other and thus burnish their reputations in their social group (*4*).

Why? Because only humans have full-blown language—and, by extension, names for one another—which allows us to share information about everyone from our immediate family members to complete strangers on the other side of the globe. We are obsessed with who does what to whom and why—we have to be to best position ourselves in the social network around us. Studies have shown that people decide on everything from which charities to sponsor to which corporate start-ups to fund based in part on reputation. My Harvard colleague Rebecca Henderson, an expert on competitive strategy in the business world, notes that Toyota gained a competitive edge over other car manufacturers in the 1980s in part because of its reputation for treating suppliers fairly.

The interplay between language and indirect reciprocity leads to rapid cultural evolution, which is central to our adaptability as a species. As the human population expands and the climate

TIM FLACH *Getty Images (ants)*; REBECCA YALE *Getty Images (lions)*



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changes, we will need to harness that adaptability and figure out ways to work together to save the planet and its inhabitants. Given our current environmental track record, our odds of meeting that goal do not look great. Here, too, game theory offers insights. Certain cooperative dilemmas that involve more than two players are called public goods games. In this setting, everyone in the group benefits from my cooperation, but all else being equal, I increase my payoff by switching from cooperation to defection. Thus, although I want others to cooperate, my "smart" choice is to defect. The problem is that everyone in the group thinks the same way, and so what begins as cooperation ends in defection.

In the classic public goods scenario known as the Tragedy of the Commons, described in 1968 by the late ecologist Garrett Hardin, a group of livestock farmers who share grazing land allow their animals to overgraze on the communal turf, despite knowing that they are ultimately destroying everyone's resource, including their own. The analogies to real-world concerns about natural resources—from oil to clean drinking water—are obvious. If cooperators tend to defect when it comes to custodianship of communal assets, how can we ever hope to preserve the planet's ecological capital for future generations?

GETTY IMAGES *(cells)*; OSCAR TARNEBERG *Getty Images (monkeys)*

ALL FOR ONE

THANKFULLY, not all hope is lost. A series of computerized experiments conducted by Manfred Milinski of the Max Planck Institute for Evolutionary Biology in Plön, Germany, and his colleagues have revealed several factors that motivate people to be good stewards of the commons in public goods games. The researchers gave each subject €40 and had them play a game via computer in which the object was to use the money to keep the earth's climate under control. Participants were told that for each round of the game, they had to donate some of their money into a common pool. If at the end of 10 rounds there was €120 or more in the common pool, then the climate was safe and the players would go home with the money they had left over. If they raised less than €120, then the climate would break down and everyone would lose all their money.

Although the players often failed to save the climate, missing the mark by a few euros, the investigators observed differences in their behavior from round to round that hint at what inspires generosity. The researchers found that players were more altruistic when they received authoritative information about climate research, indicating that people need to be convinced that there really is a problem to make sacrifices for the greater good. They also acted more generously when they were allowed to make their contributions publicly rather than anonymously—that is, when their reputation was on the line. Another study by researchers at Newcastle University in England underscored the importance of reputation by finding that people are more generous when they feel they are being watched.

These factors come into play every month when I receive my home's gas bill. The bill compares my household's consumption with both the average household gas consumption in my neighborhood outside Boston and that of the most efficient homes. Seeing how our usage stacks up against our neighbors' motivates my family to use less gas: every winter we try to lower the temperature in the house by one degree Fahrenheit.

Evolutionary simulations indicate that cooperation is intrinsically unstable; periods of cooperative prosperity inevitably give way to defective doom. And yet the altruistic spirit always seems to rebuild itself; our moral compasses somehow realign. Cycles of cooperation and defection are visible in the ups and downs of human history, the oscillations of political and financial systems. Where we humans are in this cycle right now is uncertain, but clearly we could be doing a better job of working together to solve the world's most pressing problems. Game theory suggests a way. Policy makers should take note of indirect reciprocity and the importance of information and reputation in keeping defectors in check. And they should exploit the capacity of these factors to make better cooperators of us all in the mother of all public goods games: the seven-billion-person mission to conserve the rapidly dwindling resources of planet Earth. SA

MORE TO EXPLORE

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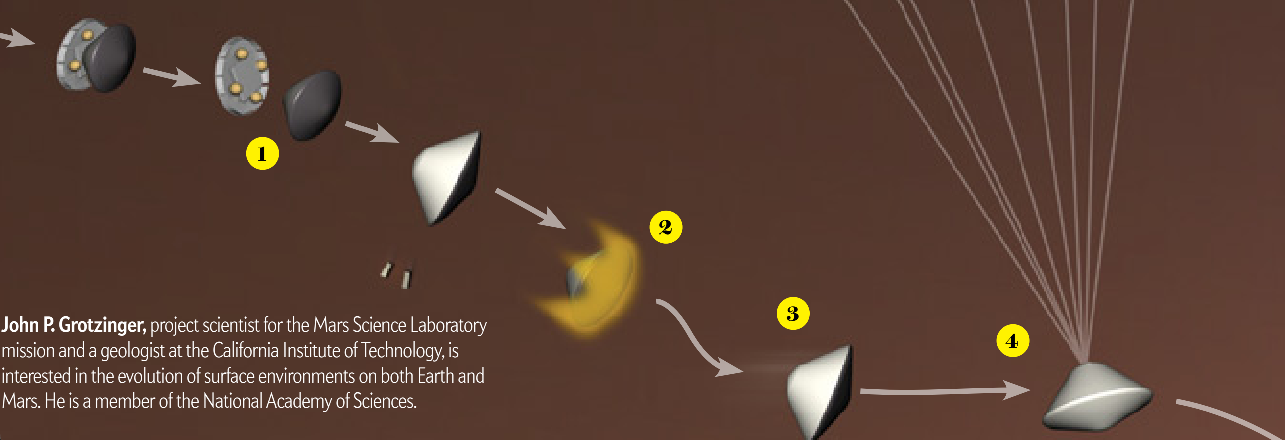
View a slide show of cooperative species at
ScientificAmerican.com/jul2012/cooperation



John P. Grotzinger, project scientist for the Mars Science Laboratory mission and a geologist at the California Institute of Technology, is interested in the evolution of surface environments on both Earth and Mars. He is a member of the National Academy of Sciences.

Ashwin Vasavada, deputy project scientist, is thrilled with the idea that someday people will be able to hike up Mount Sharp on Mars and retrace the path of Curiosity. Based at the NASA Jet Propulsion Laboratory, he also participated in the Galileo, Cassini and Lunar Reconnaissance Orbiter missions.

SPACE

READING THE RED PLANET

At 10:31 P.M. Pacific time on August 5, NASA's Curiosity rover will begin the first direct search for habitable environments on Mars

By John P. Grotzinger and Ashwin Vasavada

ALL SCIENCE BEGINS IN A *STAR TREK* MODE: GO WHERE NO one has gone before and discover new things without knowing in advance what they might be. As researchers complete their initial surveys and accumulate a long list of questions, they shift to a Sherlock Holmes mode: formulate specific hypotheses and develop ways to test them. The exploration of Mars is now about to make this transition. Orbiters have made global maps of geographic features and composition, and landers have pieced together the broad outlines of the planet's geologic history. It is time to get more sophisticated.

Our team has built the Mars Science Laboratory, also known as the Curiosity rover, on the hypothesis that Mars was once a habitable planet. The rover carries an analytic laboratory to test that hypothesis and find out what happened to the early clement environment we believe the planet had. Loosely defined, a habitable environment has water, energy and carbon. Past missions have focused on the first requirement and confirmed that Mars had—and occasionally still has—liquid water [see "The Red Planet's Watery Past," by Jim Bell; SCIENTIFIC AMERICAN, December 2006]. Those missions have also seen hints of geochemical gradients that would provide energy for metabolism. But none has seen carbon in a form potentially suitable for life.

Like the twin Viking landers of the mid-1970s, Curiosity carries a gas chromatograph/mass spectrometer capable of sensing organic compounds, whether biological or abiological in origin. Unlike Viking, however, Curiosity is mobile and is touching down in a far more promising site. More important than finding carbon itself, the mission aims to discover how to conduct the search. Even on Earth, we are not entirely sure how to trawl the deep geologic record for preserved biosignatures. Paradoxically, the very characteristics that make so many environments habitable—water, oxidants, and chemical and temperature gradients—also tend to destroy organic compounds. Paleontologists have learned to seek the rare circumstances that facilitate preservation, such as geochemical conditions that favor very early mineralization. Silica, phosphate, clay, sulfate and, less commonly, carbonate are all known to entomb organics as they precipitate. Orbiters have made maps of some of these minerals at Curiosity's landing site, which will guide its perambulations. SA

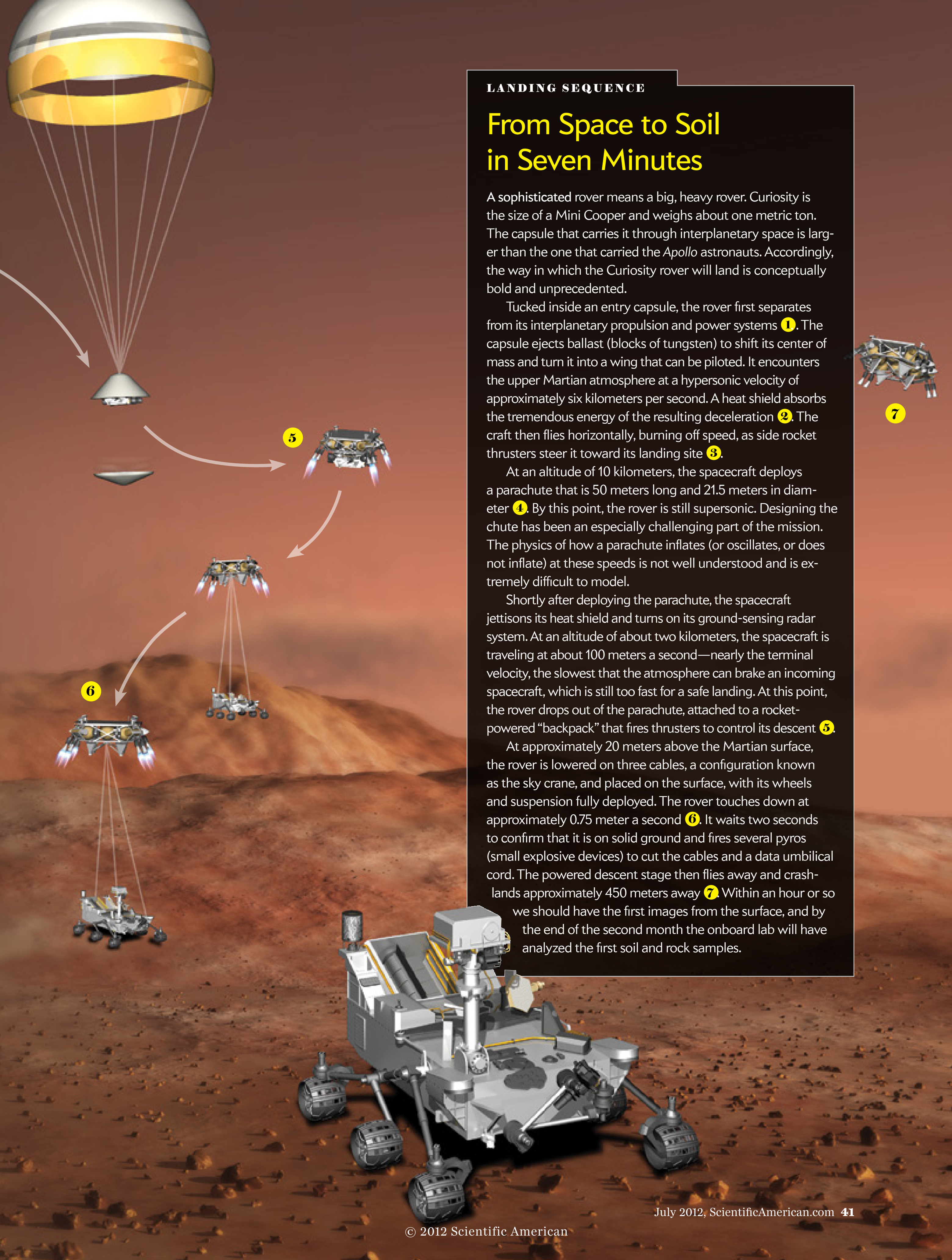
IN BRIEF

After decades of focusing on Mars's geology and hydrology, planetary scientists now plan to search more specifically for signs the planet ever had the conditions to sustain life.

The Curiosity rover will scour Gale Crater for organic compounds and attempt to settle a decades-old debate over whether these compounds can survive on the Martian surface.

The rover will set several records: largest capsule to enter a planetary atmosphere; first use of a helicopter-style sky crane to land a craft; and most sophisticated automated chemical lab ever sent to another planet.

Illustrations by Don Foley



LANDING SEQUENCE

From Space to Soil in Seven Minutes

A sophisticated rover means a big, heavy rover. Curiosity is the size of a Mini Cooper and weighs about one metric ton. The capsule that carries it through interplanetary space is larger than the one that carried the *Apollo* astronauts. Accordingly, the way in which the Curiosity rover will land is conceptually bold and unprecedented.

Tucked inside an entry capsule, the rover first separates from its interplanetary propulsion and power systems ❶. The capsule ejects ballast (blocks of tungsten) to shift its center of mass and turn it into a wing that can be piloted. It encounters the upper Martian atmosphere at a hypersonic velocity of approximately six kilometers per second. A heat shield absorbs the tremendous energy of the resulting deceleration ❷. The craft then flies horizontally, burning off speed, as side rocket thrusters steer it toward its landing site ❸.

At an altitude of 10 kilometers, the spacecraft deploys a parachute that is 50 meters long and 21.5 meters in diameter ❹. By this point, the rover is still supersonic. Designing the chute has been an especially challenging part of the mission. The physics of how a parachute inflates (or oscillates, or does not inflate) at these speeds is not well understood and is extremely difficult to model.

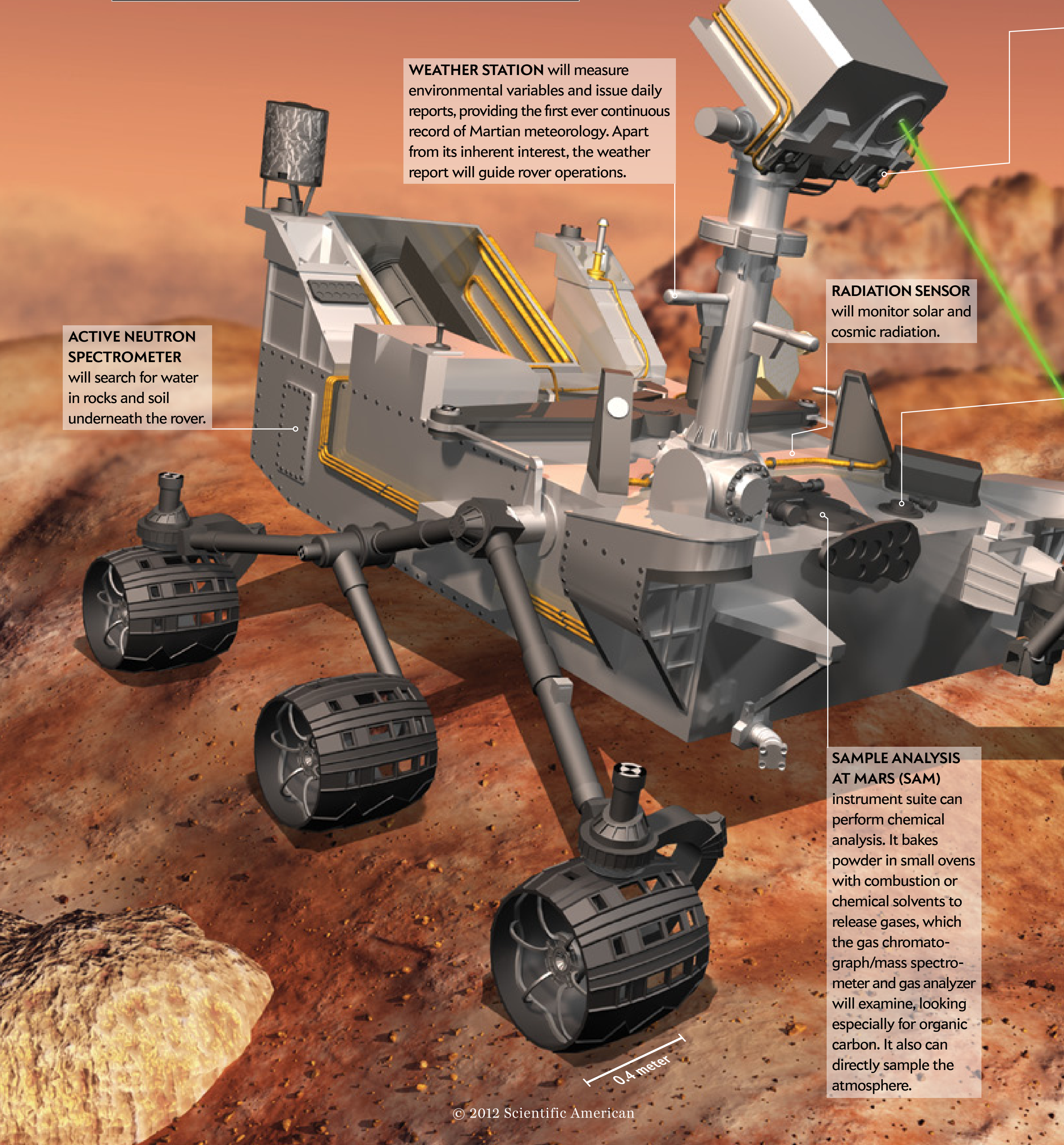
Shortly after deploying the parachute, the spacecraft jettisons its heat shield and turns on its ground-sensing radar system. At an altitude of about two kilometers, the spacecraft is traveling at about 100 meters a second—nearly the terminal velocity, the slowest that the atmosphere can brake an incoming spacecraft, which is still too fast for a safe landing. At this point, the rover drops out of the parachute, attached to a rocket-powered "backpack" that fires thrusters to control its descent ❺.

At approximately 20 meters above the Martian surface, the rover is lowered on three cables, a configuration known as the sky crane, and placed on the surface, with its wheels and suspension fully deployed. The rover touches down at approximately 0.75 meter a second ❻. It waits two seconds to confirm that it is on solid ground and fires several pyros (small explosive devices) to cut the cables and a data umbilical cord. The powered descent stage then flies away and crash-lands approximately 450 meters away ❼. Within an hour or so we should have the first images from the surface, and by the end of the second month the onboard lab will have analyzed the first soil and rock samples.

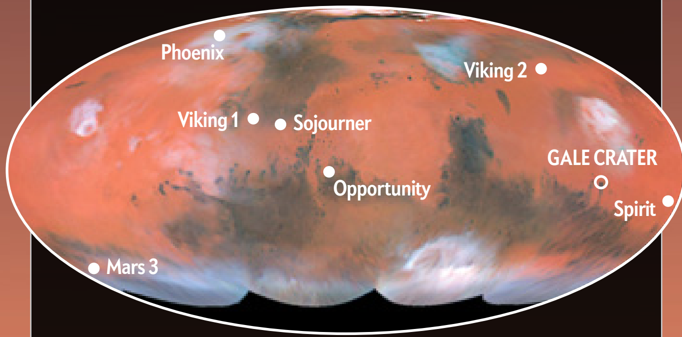
INSTRUMENTS

Leaving No Stone Unturned

Curiosity's instrument suite is designed to examine rocks, soil and atmosphere for clues to past and present habitable environments. The instruments do that by measuring chemical and mineralogical composition in various complementary ways.



LANDING SITES



STEVE LEE *University of Colorado;* JIM BELL *Cornell University;* MIKE WOLFF *Space Science Institute;* AND NASA *(Mars base map)*

Gale Crater

Following five years of study that began with an initial list of more than 50 candidates, NASA selected Gale Crater as Curiosity's landing site. Within this ancient impact crater, wind erosion over the aeons, coupled with recent impacts, has exposed once buried materials, ancient river deposits that provide records of flowing surface water, and mineral-rich fractured terrains analogous to those that, on Earth, lie above groundwater aquifers.

The 150-kilometer crater is dominated by a central mountain that rises more than five kilometers above the plains. Most or all of this peak, known informally as Mount Sharp, is accessible to the rover via a series of paths that lead from the center of the landing area. The rover will begin driving up six to 12 months after landing. The mountain is built of sedimentary rock strata that can be read like a book, from bottom to top, to generate a chronology of early Martian history starting at some point after the formation of the enormous crater the mountain fits in. The Opportunity rover has examined 15 to 20 meters of strata in its eight years of operation—not long enough on its own to reveal the evolution of Mars's climate but long enough to provide a taste of what Curiosity will see.

Sedimentary rocks precipitated from water are particularly important and might preserve signatures of past life, if there was any. By delving into Martian history, Curiosity will indirectly illuminate a period of Earth's history that has been almost entirely lost from our geologic record, a time when both planets may not have been so distinct, before Mars began its inexorable decline and Earth began to blossom. After all, the ultimate goal of planetary science is to understand our own home world better.

MORE TO EXPLORE

Mars 3-D: A Rover's-Eye View of the Red Planet. Jim Bell. Sterling, 2008.

Beyond Water on Mars. John Grotzinger in *Nature Geoscience,* Vol. 2, pages 231–233; April 2009.

Paleoclimate of Mars as Captured by the Stratigraphic Record in Gale Crater. R. E. Milliken, J. P. Grotzinger and B. J. Thomson in *Geophysical Research Letters,* Vol. 37, Article No. L04201; February 19, 2010.

Mars Science Laboratory Web site: **http://marsprogram.jpl.nasa.gov/msl**

SCIENTIFIC AMERICAN ONLINE
For an interactive illustration, go to **ScientificAmerican.com/jul2012/mars-rover**

HEALTH

SECRETS OF THE HIV CONTROLLERS

A rare group of HIV-positive individuals need no medicine to keep the virus in check. Their good fortune could point the way to more powerful treatments—and perhaps a vaccine

By Bruce D. Walker

Photographs by Richard Renaldi

UNIQUE STATUS: The genetic makeup of the individuals shown here has allowed them to fight the virus to a standstill without needing combination anti-HIV therapy. Scott Wafrock (*top left*) has lived with HIV for 26 years, Bob Massie (*top right*) for 34 years and Loreen Willenberg (*bottom right*) for 20 years. Doug Robinson (*bottom left*) learned he was HIV-positive in 2003.

Bruce D. Walker saw his first AIDS patient in 1981 while still a medical resident. He is now director of the Ragon Institute in Boston, a professor of medicine at Harvard Medical School, and an adjunct professor at the University of KwaZulu-Natal in Durban, South Africa.

ONE DAY IN EARLY 1995 A MAN NAMED BOB MASSIE WALKED INTO MY office at the outpatient clinic of Massachusetts General Hospital in Boston. Massie told me he had been infected with HIV—the virus that causes AIDS—for 16 years and yet had never shown any symptoms. My physical examination confirmed he was healthy, in stark contrast to all other patients I saw that day. At that time, a new combination of drugs was being tested that would eventually slow the progressive decline in immune function that HIV caused. In 1995, however, most people who had been infected with HIV for a decade or more had already progressed to AIDS—the stage marked by the inability to fight off other pathogens. The young man standing before me had never taken anti-HIV medication and strongly believed that if I learned the secret to his good fortune, the information could help others to survive what was then generally thought to be a uniformly fatal disease.

Massie was born with hemophilia, a blood-clotting disorder. In those days, nearly all hemophiliacs were HIV-positive because they were infused repeatedly with blood products agglomerated from thousands of donors—none of whom were screened for HIV until the mid- to late 1980s. (Today hemophiliacs receive artificial clotting factors, which pose no risk of HIV contamination.) Some of Massie's blood samples that had been stored for a study revealed that he had contracted HIV in 1978. Yet every test I conducted on him or his stored samples showed that the amount of virus in his blood was vanishingly small and that his immune responses seemed as strong as ever.

I was stunned. This was the first time I had ever come face to face with a patient whose body appeared to be controlling HIV on its own and had been doing so for a decade and a half. Massie, as it turned out, was not alone. Investigators in California, Maryland, Italy and France had all come across similarly unusual individuals in the early 1990s and were studying them intently. We eventually determined that these extraordinary people divided into two main groups: one set of "long-term nonprogressors," whose bodies were able to fight off an HIV infection for an extra long time but who ultimately became ill, and a much smaller group of even more astonishing "elite HIV controllers," who, like Massie, simply did not develop AIDS year after year after year despite never having taken any anti-HIV medication.

Somehow the elite controllers maintain extremely low—or even undetectable—levels of virus in their blood. If scientists can

IN BRIEF

One out of 300 people infected with HIV are naturally able to control the virus without having to take antiviral medications.

Investigators believe the key to the good fortune of such elite controllers lies in the complex workings of their immune system.

Genetic studies reveal the precise reasons why the targeting and destruction of HIV-infected cells occur more quickly in the body of an elite controller.

Understanding this efficient, powerful immune response in greater detail might one day lead to better methods for preventing and treating AIDS.

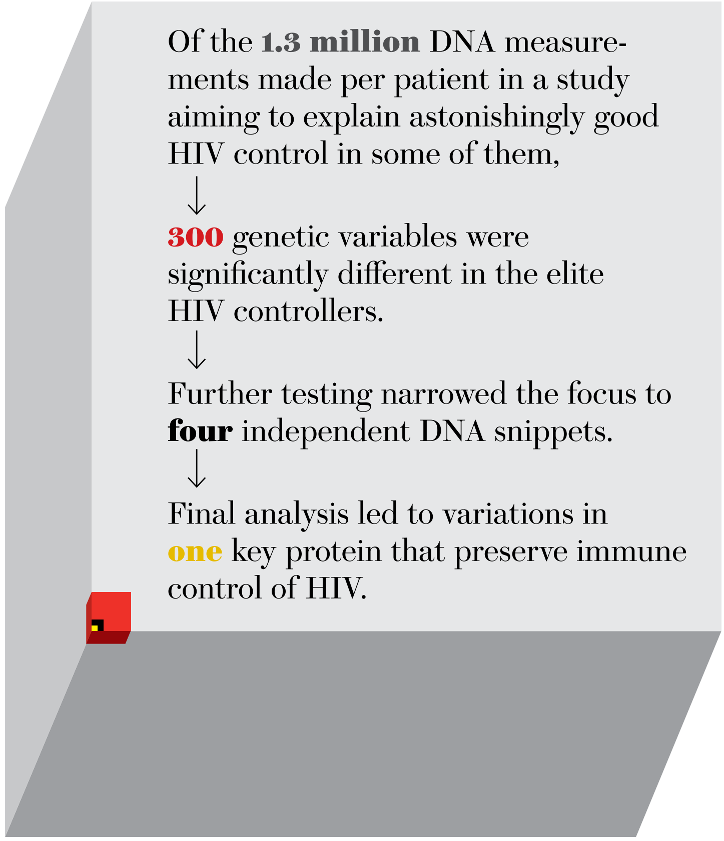


figure out how these rarest of rare individuals can pull off such a feat, they may learn how to create an effective vaccine or develop therapies that strengthen a patient's immune system, as opposed to just attacking the virus with drugs.

Such an accomplishment would come not a moment too soon. Currently about 33 million people are living with HIV worldwide. More than six million of them have access to anti-HIV medication, but these drugs are unable to cure HIV infection, and they must be taken for life. The likelihood is slim that drug treatment can be supplied to everyone who needs it for as long as they need it. We desperately require a solution to prevent infection in those who are not yet infected and to prevent disease from developing in those who are.

After two decades of studying elite controllers like Massie, my colleagues and I are more persuaded than ever that research into their unique biochemical makeup offers phenomenal insights for the prevention and treatment of AIDS. This scientific journey has broad implications for the ultimate ability to harness the human immune system to combat a myriad of other human infectious diseases and perhaps even some cancers.

NOT ENOUGH GENERALS

TO UNDERSTAND how unusual Massie and other elite HIV controllers are and why their story offers hope for conquering AIDS and other diseases, it helps to first understand how HIV attacks the body and how the body tries to defend itself. In the past 30 years researchers have learned that the immune systems of most people infected with HIV—not just elite controllers—fight back very hard against the initial infection, producing lots of antibodies against the virus. Unfortunately, the antibodies are not effective, which is why the infection persists—even in elite controllers. The exact mechanisms of control without good antibodies are rather convoluted and at times mysterious. Yet in essence, two different immune cells—known as helper T (or CD4+) cells and killer T (or CD8+) cells—and molecules known as human leukocyte antigen (HLA) receptors—seem to play the most important roles.

As a virus, HIV is unable to reproduce on its own. When it infects cells, it takes over their machinery and instructs them to make new viruses instead of performing their usual cellular functions. These infected cells, however, contain an early-warning system to alert the body to the invaders. In the earliest hours of a viral invasion, the infected cells ferry pieces of the viral proteins that they are being forced to manufacture up to their surface. Here these bits and pieces of foreign material are displayed by HLA receptors. The presence of viral proteins attached to the HLA molecules of these cells quickly attracts the attention of the immune system, programming the helper T cells to mobilize a group of killer T cells that are then specifically primed to destroy HIV-infected cells. The now activated helper T cells also gradually trigger the production, by yet other immune cells, of antibody molecules that latch on to specific components of the viruses being released from infected cells in a separate, though futile, attempt to eliminate the invaders.

This defensive effort works pretty well for most viral infections. Yet HIV performs an unusual trick that ultimately defeats the immune system: the virus preferentially targets helper T cells for infection, including those that are specifically primed to help defend against it. This particular act of viral sabotage leads directly or indirectly to the eventual destruction of most of the available helper T cells. If one thinks of helper T cells as the generals of the immune system and of killer T cells as the foot soldiers, then HIV takes laserlike aim at the generals, disrupting their ability to give the foot soldiers effective orders on how to proceed. In the simplest sense, HIV is an infection of the immune system, and the results are predictable: the ultimate inability of the body to defend itself, not just against HIV but against hundreds of other invaders as well.

When Bob Massie showed up in my office in the mid-1990s, my laboratory was focused on the role of the killer T cells in fighting HIV. If Massie's immune system were really controlling HIV, we surmised, he would have to have mounted an unusually strong killer T cell response. We enrolled him in a study we were conducting and quickly discovered that he had the strongest HIV-specific killer T cell response we had ever encountered. In other words, his immune system produced a large infantry specifically trained to recognize HIV. This result fit with our hypothesis, but other HIV-positive men and women also sometimes had strong killer T cell responses, and yet they went on to develop AIDS, as if the infantry could be present in large numbers but could not fight effectively.

This observation, in turn, led to a second hypothesis. Maybe Massie's killer T cells were particularly effective because they had received the appropriate directions from especially effective helper T cells. In other words, both his generals (helper T cells) and his infantry (killer T cells) were strikingly well trained.

As it happens, the first project I undertook when I began my research career in the mid-1980s examined the specific steps by which helper T cells coordinated the immune response against HIV. My colleagues and I studied blood samples from dozens of AIDS patients to look for evidence that helper T cells were orchestrating a counterattack. We found nothing, however—even after months of trying. It was almost as if the immune system was incapable of generating such a high-level response. Indeed, the lack of HIV-specific helper T cells was the most obvious hole in the defensive repertoire in HIV-infected individuals.

Yet Bob did not have AIDS. He was successfully controlling his HIV infection. We therefore dusted off the same assay I had used 10 years earlier. This time the first look revealed exactly what we had predicted would happen if the immune system was in fact controlling the infection—not only did Massie have these generals of the immune system that were specifically trained to direct a campaign against HIV, he had enormous numbers of them. We published our results in *Science* in 1997. Our paper showed that helper T cells from HIV-infected individuals could at times respond effectively to the virus, a discovery that fundamentally changed how our group looked at HIV. At long last, it seemed possible that the immune system might, in some cases, be able to get the upper hand against a virus that was killing millions of people around the globe.

MORE QUESTIONS

AS WITH MANY discoveries in science, our finding that an effective killer T cell response against HIV required a robust cadre of helper T cells generated lots of new questions and hypotheses. Had Massie actually cleared the virus from his body? The answer was no, because we could detect viral genetic material in his blood. [To learn why some people, unlike Massie, are actually immune to HIV, see "Blocking HIV's Attack," by Carl June and Bruce Levine; SCIENTIFIC AMERICAN, March.] Could Massie still be infectious to others? We did not know but had to assume he was—an important issue for him and his wife (they eventually had a daughter). Was his immune system somehow supercharged, able to fight off all invaders? The answer here, sadly, was no, because he also suffered from hepatitis C virus infection—another result of contaminated treatments for hemophilia—and his body was completely unable to control that virus. (Massie later received a liver transplant, which cured both his hepatitis and—because the new liver could make the necessary clotting factor—his hemophilia.)

We considered the possibility that every infected person actually did produce HIV-specific helper T cells but that these highly trained generals were targeted and killed in the earliest stages after the initial invasion. If that were the case, then hitting the virus early and hard with a new drug cocktail that could completely inhibit viral production should protect the helper T cells of newly exposed individuals. Such a powerful first strike would allow the immune system to quickly gain the upper hand over the virus and maintain that control as effectively as Bob's body did naturally. We performed clinical trials with a few dozen volunteers and showed that early treatment rapidly brought the amount of HIV in the blood to undetectable levels and, within a few weeks, allowed a massive scale-up in the production of helper T cells able to direct the killer T cells to combat HIV. In other words, nearly everyone's immune system was capable of producing highly trained generals (the HIV-specific helper T cells), but they were eliminated almost as soon as they were produced.

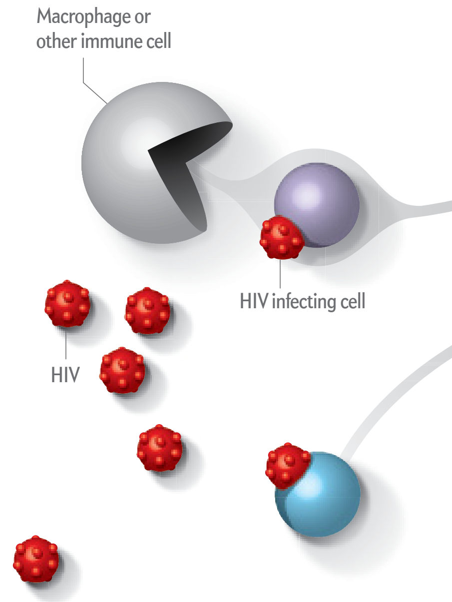
Unfortunately, the newfound protection did not produce the kind of durable immune control we were seeing in Massie. As part of a follow-up clinical trial, we stopped treatment in a handful of patients (with their informed consent and after re-

HOW CONTROLLERS FIGHT BACK

Plugging a Gap in the Body's Defenses

Unlike most people infected with HIV (*top panel*), a few rare individuals (*bottom panel*) can limit the amount of virus in their body to low or undetectable levels because their immune system is exquisitely equipped to recognize and destroy infected cells.

1 Early on, roving immune cells (such as macrophages) attack cells that have been infected by HIV and are making viral proteins.



Usual Response to HIV

Typically infection with HIV results in a long seesaw battle between the immune system and the virus, with the immune system winning the first several rounds but falling further and further behind as the years progress.

Superlative Response

Elite controllers start with the same basic immune reaction as everyone else—it just happens to be more efficient. This exceptional performance spares the rest of the immune system from harm.

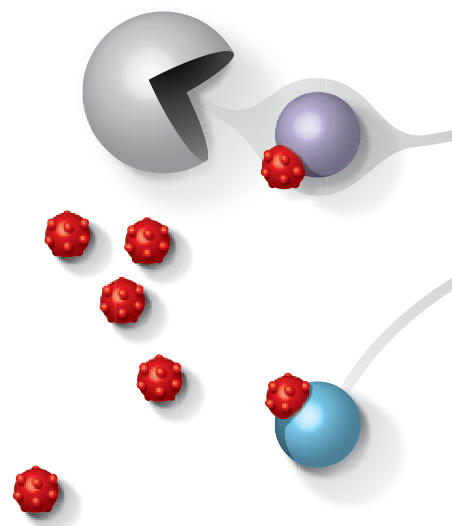
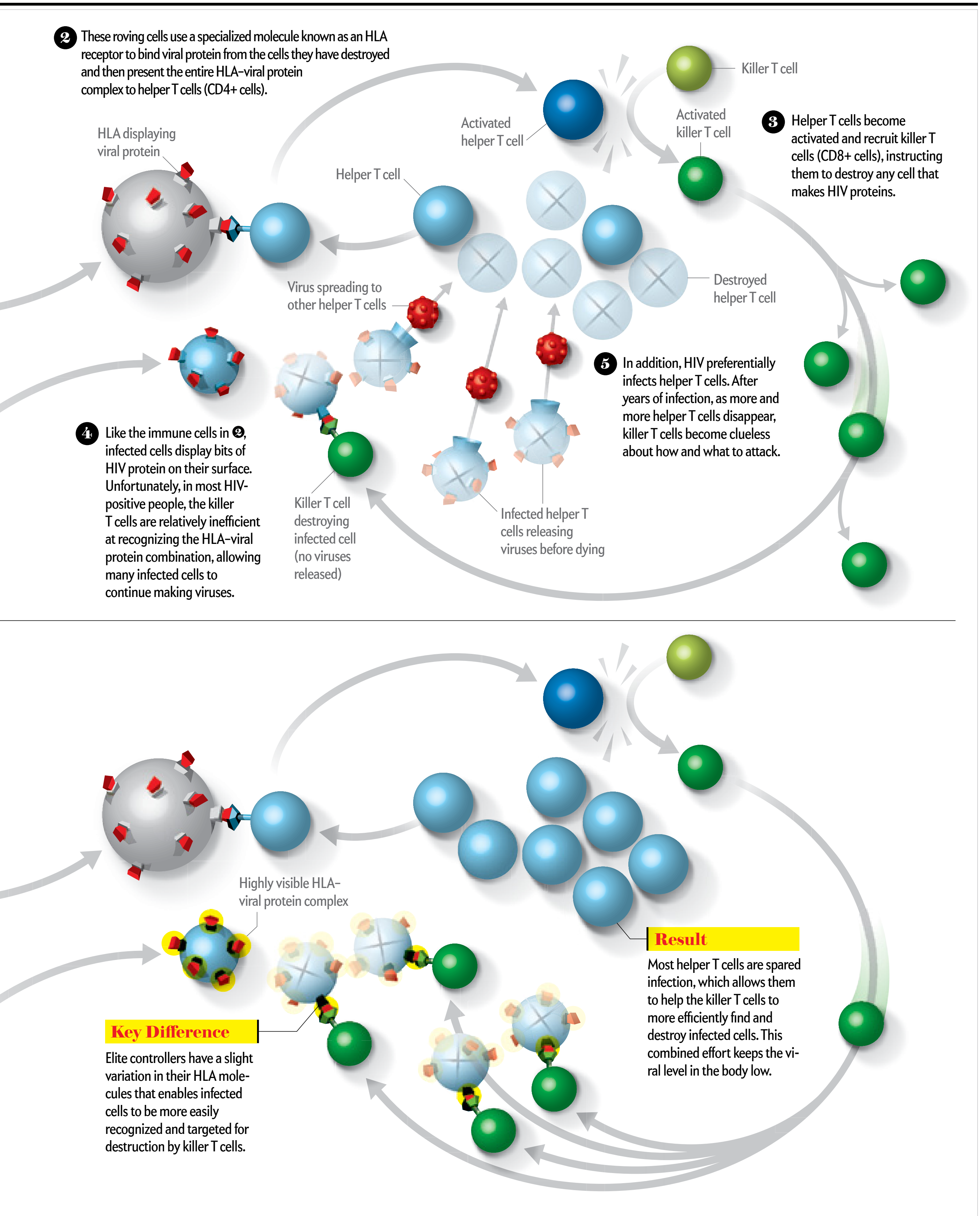


Illustration by Jen Christiansen



2 These roving cells use a specialized molecule known as an HLA receptor to bind viral protein from the cells they have destroyed and then present the entire HLA–viral protein complex to helper T cells (CD4+ cells).
HLA displaying viral protein
Helper T cell
Activated helper T cell
Killer T cell
Activated killer T cell
3 Helper T cells become activated and recruit killer T cells (CD8+ cells), instructing them to destroy any cell that makes HIV proteins.
Destroyed helper T cell
Virus spreading to other helper T cells
5 In addition, HIV preferentially infects helper T cells. After years of infection, as more and more helper T cells disappear, killer T cells become clueless about how and what to attack.
4 Like the immune cells in 2, infected cells display bits of HIV protein on their surface. Unfortunately, in most HIV-positive people, the killer T cells are relatively inefficient at recognizing the HLA–viral protein combination, allowing many infected cells to continue making viruses.
Killer T cell destroying infected cell (no viruses released)
Infected helper T cells releasing viruses before dying
Highly visible HLA–viral protein complex
Result
Most helper T cells are spared infection, which allows them to help the killer T cells to more efficiently find and destroy infected cells. This combined effort keeps the viral level in the body low.
Key Difference
Elite controllers have a slight variation in their HLA molecules that enables infected cells to be more easily recognized and targeted for destruction by killer T cells.

ceiving permission from an ethical review board). As our study subjects stayed off therapy for a year or more, most of them experienced a gradual rise in the level of virus in their blood, so that the HIV drug cocktail had to be restarted. Nevertheless, the results, which were published in *Nature* in 2000, showed that it was possible to enhance, at least temporarily, the body's control of HIV. Furthermore, the same mechanisms that allowed Massie to control his infection could be made to work in other people.

How could we make this new level of immune control more durable, more like that of the elite controllers? Up until this point, we had been looking at immune responses—helper and killer T cells—that we already knew how to measure. We needed to go deeper into the workings of the immune system to learn, once and for all, what was different about elite controllers that protected them against the ravages of HIV.

A NEW APPROACH

DIGGING DEEPER into the basis for HIV control was made possible by a series of lucky encounters. Around this time, I was invited to a dinner hosted by Lawrence Summers, then president of Harvard University, to discuss the school's expanding mission in global health. Also attending the dinner was Eric Lander, a former classmate of Massie's at Princeton University and an expert in applying the latest advances in human genetics to medical research. I had never before met Lander—the leader of the then newly established Broad Institute, a joint endeavor of Harvard and the Massachusetts Institute of Technology—but had long wanted to because it seemed that his new technology might provide insights into the HIV problem.

Our mutual acquaintance with Massie was the starting point for an extended conversation that night on the sidewalk outside Summers's house. Lander explained that it was possible to compare the DNA of different people—specifically using natural variations in the A, T, C, G letters of the DNA code called SNPs (for single-nucleotide polymorphisms)—to try to identify genetic influences on an individual's responses to a disease. The SNPs would function as pointers—or markers—for sections of the genome of elite controllers like Massie that allowed them to keep damage from HIV infection to a minimum. If we could find a unique pattern of SNPs that was associated with control, the pattern might help us locate the genes that were responsible, if they existed. To do these studies, we would need to obtain a swab of saliva or a blood sample from elite controllers and HIV-positive patients who had progressed to AIDS and then extract some DNA from those samples. At a minimum, we would need to sort through about one million SNPs for each of perhaps 1,000 elite controllers and about twice as many AIDS patients to get an adequate statistical sample.

Obtaining DNA from large numbers of people with AIDS was certainly not a problem. The issue that seemed insurmountable was finding large numbers of elite controllers. By this time we and other researchers around the world knew of a handful of such unusual people, but the idea of finding 1,000 elite HIV controllers was more than daunting.

At about this same time, I was invited to give a lecture in New York City to a group of 300 health care providers who had large HIV practices. My assigned task was to update these clinicians on what we knew about how HIV causes AIDS. During my talk, I happened to mention the case of Massie—someone who at that time had been infected for nearly a quarter of a century, who had never been treated, who still had a normal helper T cell count and undetectable amounts of virus in his blood. (At that point, testing for HIV had become much more sensitive, detecting as few as 50 copies of the virus per milliliter of blood. And Massie was always below this number.) On a whim, I asked for a show of hands as to whether any of the physicians or nurses in the audience had ever seen such a case.

I must have audibly gasped when more than half of the people in the room raised their hands. Here was the answer to our problem of finding 1,000 elite HIV controllers! Through the health care providers in this auditorium alone, we could potentially reach 200 of these unusual individuals. If we could go directly to physicians and nurses in private practice across the country and ask them to refer their HIV controllers to us, we believed we could easily reach the number necessary to perform a statistically significant search to determine whether specific genetic variants existed that either boosted or impaired the immune system's ability to fight HIV to a permanent standstill.

Massachusetts General Hospital (MGH) gave us the institutional approval to proceed with such a study. We quickly hit another roadblock, however. Our requests for funding from numerous agencies and organizations went nowhere. They seemed to think our goals were too vague because we did not know what we were looking for and the odds of success seemed minuscule.

As we were struggling with this disappointing stall, Mark Schwartz, a former chairman of Goldman Sachs (Asia), invited me to breakfast with him at a hotel in New York City. Schwartz and his wife, Lisa, had begun to fund some of MGH's and Harvard's efforts to train scientists and clinicians in Africa to help tackle the AIDS crisis. During our meeting, Schwartz asked me what else I was working on. While answering, I expressed my frustration over the elite controller project and noted that I saw it as holding key information to guide our path forward. Schwartz immediately perked up when I explained the logic for the study. Why didn't he and his wife fund it, he asked. To my amazement, by the time we parted the Schwartzs had made a commitment of $2.5 million over the next five years to launch our study of elite HIV controllers. The funds would be spent to recruit patients from across the country, and we would point to their successful enrollment to convince other funders to pay for the genetic analyses.

We immediately began the study, contacting all the major HIV doctors and nurses across the U.S. and eventually collecting DNA samples from patients in Europe, Asia, Australia and South America. We tried to include elite controllers from Africa but had trouble finding them because viral testing of blood was not routinely performed in many African countries at that time. Florencia Pereyra, a physician-scientist at Harvard Medical School, organized the colossal recruitment effort with the aid of at first one, then two and, later, three assistants. The Bill & Melinda Gates Foundation provided us with a five-year grant for $20 million to complete the studies.

It took almost as long to process and analyze the data as to collect the specimens. For each of the 974 elite controllers and 2,648 progressors in our study, we measured about 1.3 million SNPs in their DNA with an automated chip system. We relied on massive computing services at the Broad Institute to make comparisons between the two groups' SNPs. Paul DeBakker, who

SURVIVOR: **Infected for perhaps 35 years, Steven Muench still does not need anti-HIV medication—although the level of virus in his blood has crept up a bit in the past decade.**

is a geneticist at the institute, led the computational analysis.

By 2009 we had an initial answer. Of the three billion nucleotides in the human genome, there were 300 SNPs that were significantly different in elite controllers compared with people who were much more susceptible to developing AIDS. Further analysis whittled these 300 SNPs down to a mere four that were independently highly correlated with control of the infection. All four lay within chromosome 6, which is known to contain many genes that affect immune function. But we still did not know which gene, or genes, was important and why.

At least we now knew where to look. Next we needed to determine the complete genetic sequence of the region of chromosome 6 that our SNPs told us was important. Although we did not have funding to do this additional detailed sequencing, a remarkable medical student, Xiaoming "Sherman" Jia , solved the problem for us. Using massive data sets from other large genetic studies, he was able to develop a computer algorithm that, based on the combination of SNPs in each person, accurately inferred the sequence of DNA nucleotides, or code letters, for this particular stretch of the chromosome and, in turn, the sequence of amino acids in a protein encoded by the DNA in that region.

Like going to higher power on a microscope, Sherman's analysis suddenly brought the picture into crisp view. The major genetic difference between elite HIV controllers and progressors came down to a change in amino acids that affected the shape in a groove of the HLA receptors that sat on the surface of infected cells. This particular groove held the bits of HIV proteins that are displayed by the HLA receptor. Something about this shape made the HLA-HIV combination on infected cells in elite controllers extraordinarily good for being seen by killer T cells, which then destroyed the infected cell. It is as if a factory worker, wanting to notify the outside community that the plant has been taken over by terrorists who are making bombs, paints his hand and a piece of the bomb bright orange and then waves them out the window for passersby to see. His action helps the authorities notice that something bad is happening, so they can come in and take care of the threat.

Here, at last, was another missing piece of the puzzle and the reason why Massie and other elite controllers are still healthy after all these years. From the earliest days of their infection, their immune systems maintain a critical number of healthy HIV-specific helper T cells, which provide vital instructions to the newly activated killer T cells. These foot soldiers of the immune system, in turn, are able to effectively find and destroy HIV-infected cells because the HLA molecules on the surfaces of those doomed cells are genetically endowed to advertise the presence of the invader to killer T cells better than the HLA molecules of the vast majority of people.

As a consequence, by keeping viral levels low, these highly efficient killer T cells protect the remaining helper T cells from infection. The foot soldiers guard the generals, allowing the immune system to fight the virus to a standstill. Our long-shot genetic approach—which began with no clear hypothesis and depended on the collaboration of more than 300 investigators around the world—revealed that the major genetic basis for durable control of HIV infection came down to the characteristics of a single protein, the HLA molecule.

Once again, the findings, which were published in *Science* in 2010, have raised new questions. We need to figure out how to re-create the elite controllers' immune response in most infected people. In addition, we are beginning to understand just what it takes to fine-tune the body's defenses against specific illnesses, starting with the need to boost the appropriate actions by helper and killer T cells. [To learn more about T cell therapy in cancer, see "A New Ally against Cancer," by Eric von Hofe; Scientific American, October 2011.]

The immune system has long been a powerful if imperfect partner in the fight against disease. We still have much to learn, but soon, we hope, we will be able to help it fill in the gaps. SA

MORE TO EXPLORE

The Major Genetic Determinants of HIV-1 Control Affect HLA Class I Peptide Presentation. International HIV Controllers Study in *Science*, Vol. 330, pages 1551–1557; December 10, 2010. www.ncbi.nlm.nih.gov/pmc/articles/PMC3235490

Immunogenetics of Spontaneous Control of HIV. Mary Carrington and Bruce D. Walker in *Annual Review of Medicine*, Vol. 63, pages 131–145; February 2012. www.ncbi.nlm.nih.gov/pubmed/22248321

A Song in the Night: A Memoir of Resilience. Bob Massie. Nan A. Talese, 2012.

SCIENTIFIC AMERICAN ONLINE
Walker talks about the seesaw struggle of HIV and the immune system at ScientificAmerican.com/jul2012/elite-hiv-controllers

SA IMAGES

ENGINEERING

FLEET OF FOOT

Nimble robots like this "Cheetah" will help the military navigate terrain too rocky for wheels

IN THE DECADE SINCE THE START OF COMBAT OPERATIONS in Afghanistan and Iraq, the military has relied increasingly on robots. Drones and bomb-removal bots have been designed to keep troops out of harm's way. Now the U.S. Department of Defense is looking for sleeker, faster robots that can assist with a wider range of missions.

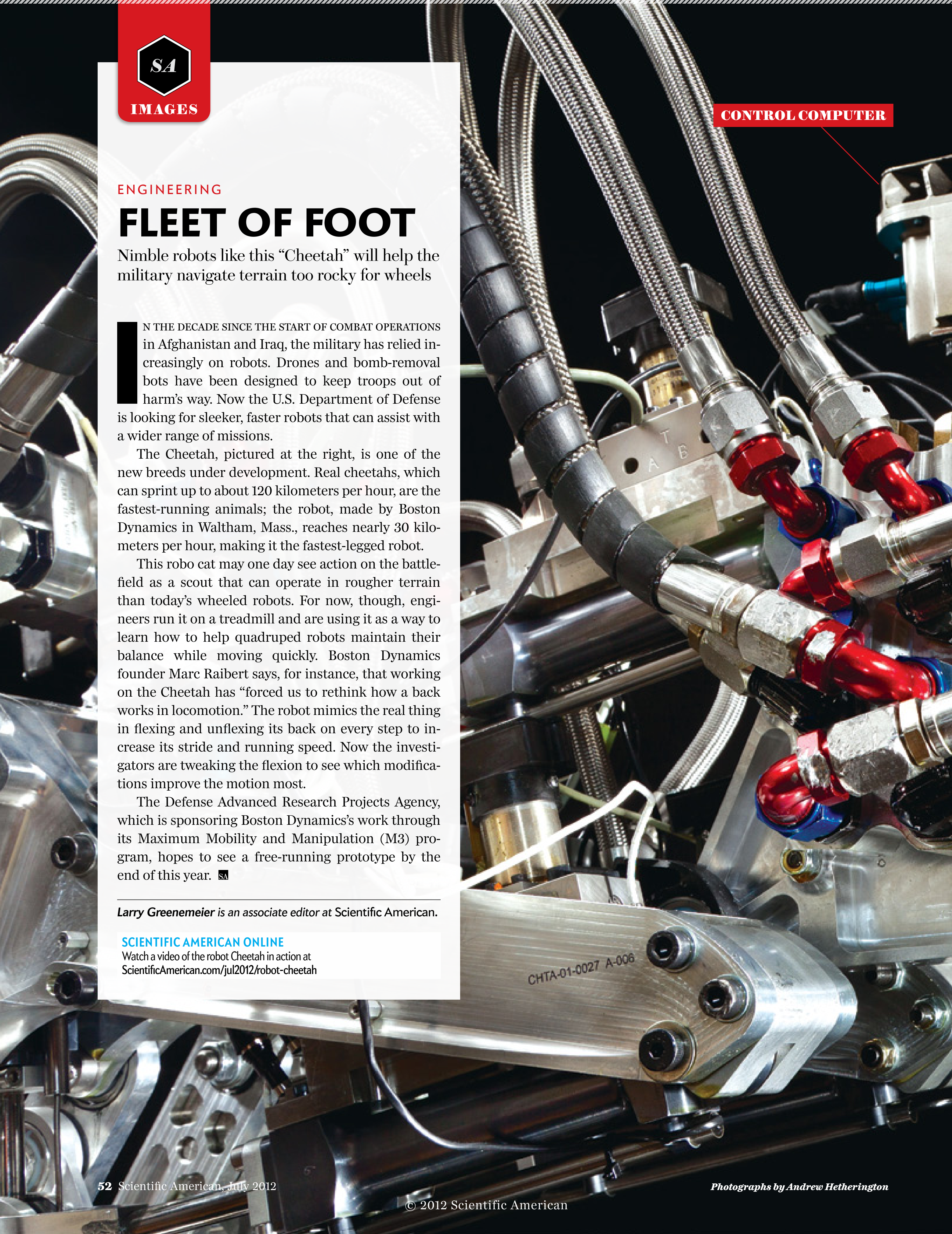
The Cheetah, pictured at the right, is one of the new breeds under development. Real cheetahs, which can sprint up to about 120 kilometers per hour, are the fastest-running animals; the robot, made by Boston Dynamics in Waltham, Mass., reaches nearly 30 kilometers per hour, making it the fastest-legged robot.

This robo cat may one day see action on the battlefield as a scout that can operate in rougher terrain than today's wheeled robots. For now, though, engineers run it on a treadmill and are using it as a way to learn how to help quadruped robots maintain their balance while moving quickly. Boston Dynamics founder Marc Raibert says, for instance, that working on the Cheetah has "forced us to rethink how a back works in locomotion." The robot mimics the real thing in flexing and unflexing its back on every step to increase its stride and running speed. Now the investigators are tweaking the flexion to see which modifications improve the motion most.

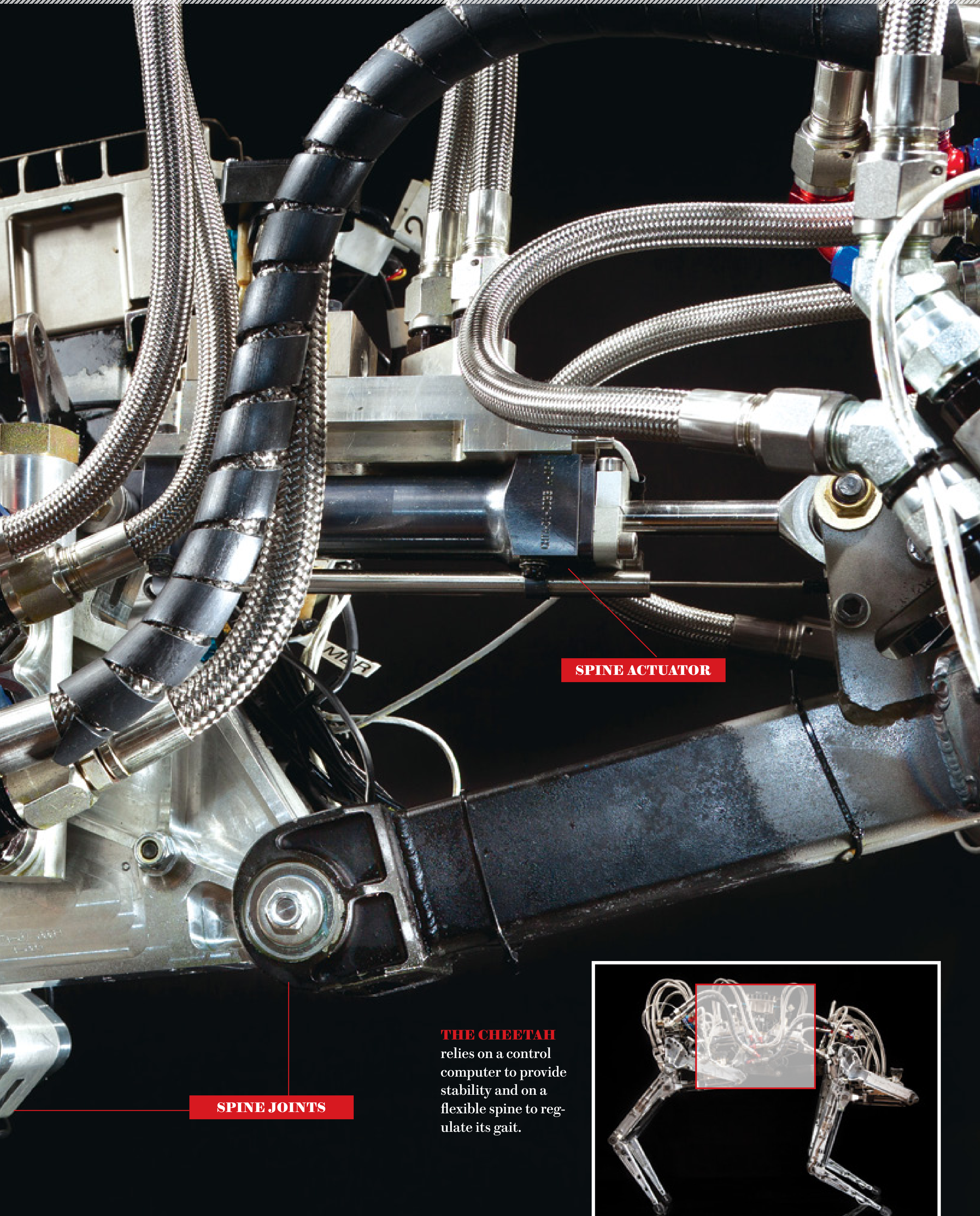
The Defense Advanced Research Projects Agency, which is sponsoring Boston Dynamics's work through its Maximum Mobility and Manipulation (M3) program, hopes to see a free-running prototype by the end of this year. SA

***Larry Greenemeier** is an associate editor at* Scientific American.

SCIENTIFIC AMERICAN ONLINE
Watch a video of the robot Cheetah in action at ScientificAmerican.com/jul2012/robot-cheetah

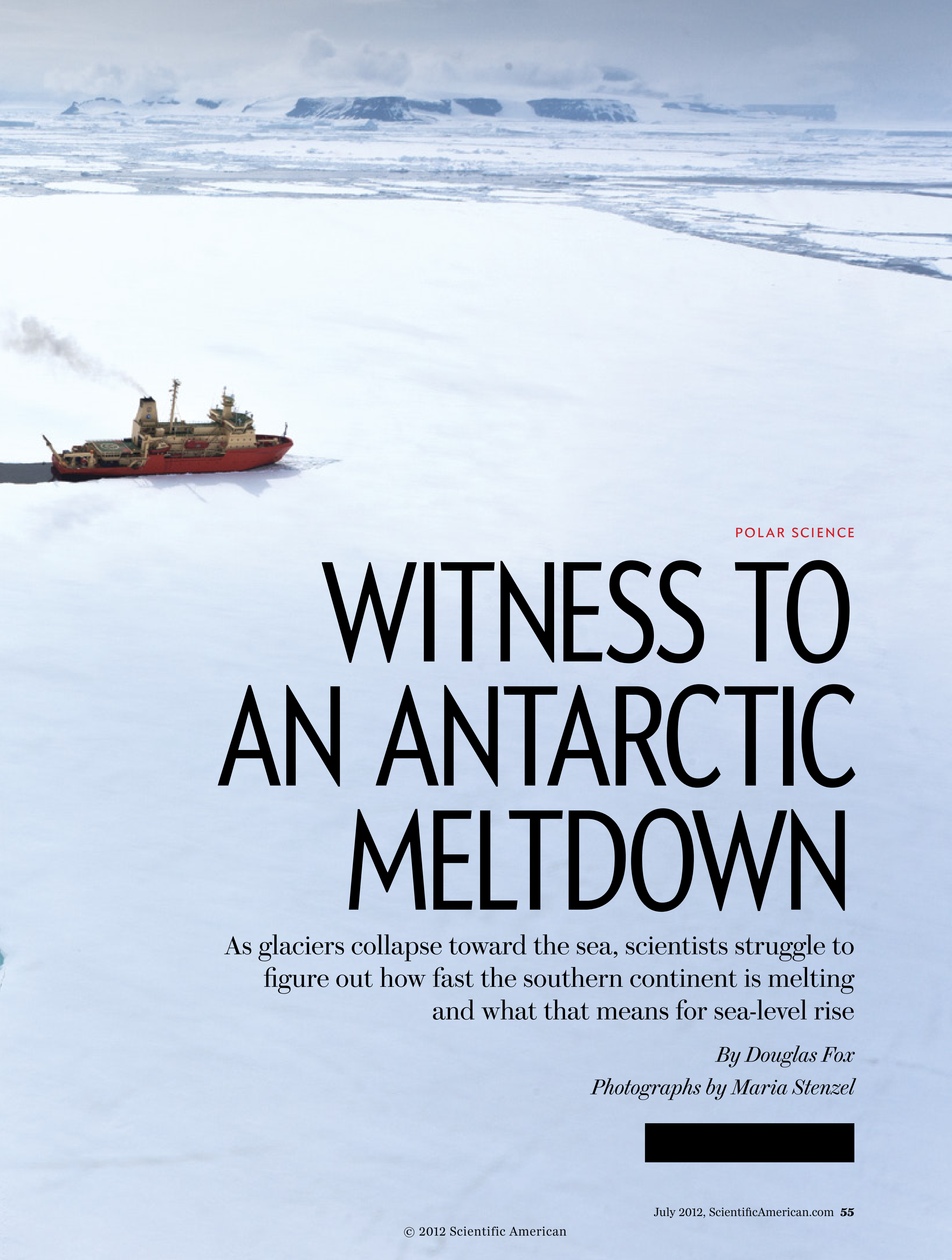


Photographs by Andrew Hetherington



THE CHEETAH relies on a control computer to provide stability and on a flexible spine to regulate its gait.

ICEBREAKER
Nathaniel B. Palmer takes scientists across the Weddell Sea near the coast of the Antarctic Peninsula.



POLAR SCIENCE

WITNESS TO AN ANTARCTIC MELTDOWN

As glaciers collapse toward the sea, scientists struggle to figure out how fast the southern continent is melting and what that means for sea-level rise

By Douglas Fox

Photographs by Maria Stenzel

[redacted]

Douglas Fox is a freelance writer in San Francisco who has written for *Popular Mechanics, Esquire* and others. His July 2011 *Scientific American* article, "The Limits of Intelligence," will appear in *The Best American Science Writing 2012* (Ecco).

IN 1995, 10 ARGENTINE SOLDIERS WITNESSED A CATACLYSM THAT NO OTHER HUMANS HAVE EVER SEEN, ONE THAT HAS SINCE ALTERED OUR UNDERSTANDING OF CLIMATE CHANGE.

The men were stationed at Matienzo Base, a dreary cluster of steel huts that sat atop a wedge of volcanic rock jutting from the sea, 50 kilometers off the coast of Antarctica. The island was surrounded by a plain of glacial ice covering 1,500 square kilometers—25 times the area of Manhattan. Although the ice shelf floated on the sea, it was 200 meters thick—as solid as bedrock. Yet Captain Juan Pedro Brückner sensed that something was wrong. Meltwater had formed ponds that dotted the ice. He could hear a gurgling sound as the water seeped down into a network of descending cracks. Day and night, Brückner's men heard deep convulsions that sounded like subway trains passing underneath their beds. The rumbles grew more and more frequent.

Then one day, while the crew ate lunch inside one of the huts, they were blasted by a boom—"calamitously loud, like a volcano blowing up," Brückner recalls. They ran outside. The ice shelf bordering their little island was breaking apart. The upheaval was so violent they feared the fracturing ice would tear the island from its foundation and roll it like a log into the ocean. They placed instruments by their feet to warn them if the ground started to tip. After a few tense days the men were evacuated by helicopter to another station 200 kilometers north. The island held, but the map had changed for good.

Brückner and his colleagues had witnessed the collapse of the Larsen A ice shelf, a signature event. All told, as warm summers have reached farther down from the bottom of South America into the northernmost section of the Antarctic Peninsula, four ice shelves on the eastern side of the peninsula, including Larsen A, have collapsed in a striking pattern from the northern tip southward toward the Antarctic mainland.

Once a shelf disappears, towering glaciers that had piled up behind it in fjords along the sea's edge are free to slide into the ocean. And slide they do, adding substantial volume to the sea. Scientists still do not know what triggers the breakup of an ice shelf or when future ones will occur, so they struggle to estimate how quickly glaciers will dump their ice into the ocean and therefore how much sea level will rise. Although the landmark 2007 report by the Intergovernmental Panel on Climate Change (IPCC) estimated that sea level will rise by just 18 to 59 centimeters by 2100, glaciologists worry that increasingly quick climate change could accelerate glacier melt 10-fold, thus pushing sea level much higher than anticipated. The ice shelf breakups might just provide that feedback.

The Antarctic Peninsula holds only a small fraction of the continent's ice, but it is "a natural laboratory," says Theodore Scambos, a glaciologist at the National Snow and Ice Data Center in Boulder, Colo. "It's the trailer for the movie that's going to unfold over the rest of Antarctica for the next 50 to 100 years."

Understanding this natural experiment has become an urgent priority. Scientists need to know how fast the ice shelves are disintegrating and what is causing the demise so that they can better estimate future sea-level rise. "Time and again, the models are conservative, and they're underestimating the mag-

IN BRIEF

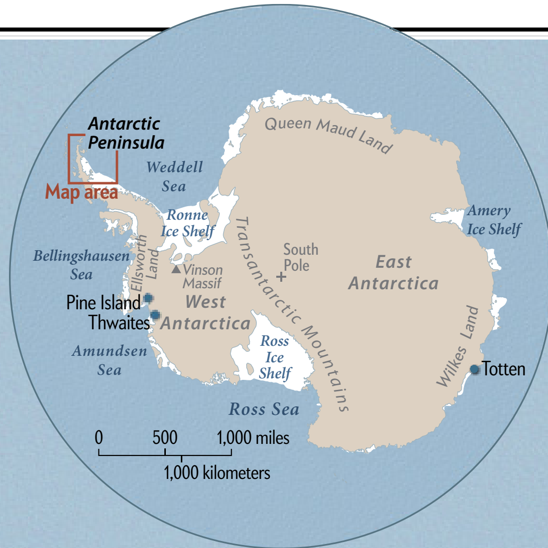
Massive ice shelves that cling to the edges of Antarctica are breaking apart, and their collapse is allowing enormous glaciers behind them to slide into the ocean, raising sea level.

Scientists need to better understand why and how fast the ice shelves are disintegrating so that they can better estimate future sea-level rise.

Satellite data about glaciers are not detailed enough for accurate estimates. Scientists have made recent expeditions to Antarctica to install instruments that will give them the information they need. Author Douglas Fox accompanied them on an eventful eight-week trip and documents that experience here. He also describes the data now streaming in and what they predict for the planet.

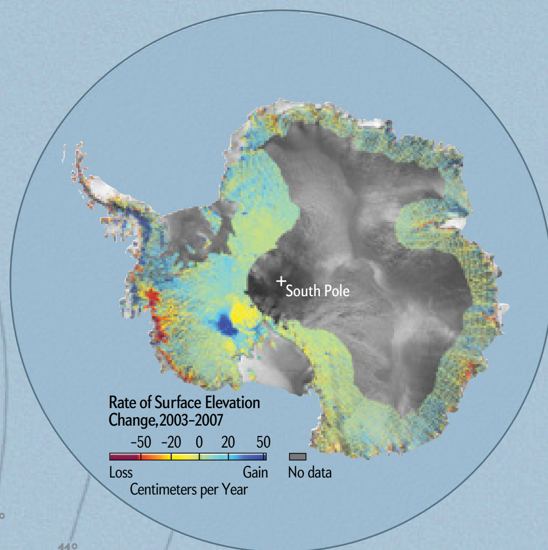
Less Ice, More Snow

Change is rapid along the Antarctic Peninsula (*below*), where annual air temperatures are rising and glaciers are accelerating toward the sea (*bottom*). Inland elevation is up in spots because of more snowfall (*below, right*), but Antarctica still loses up to 190 billion metric tons of ice a year.



Temperatures Rise

Massive ice shelves have been crumbling in a pattern from north to south, as a mean annual temperature line of –9 degrees Celsius advances in that direction. Scientists predict the Scar Inlet ice shelf will disappear next.

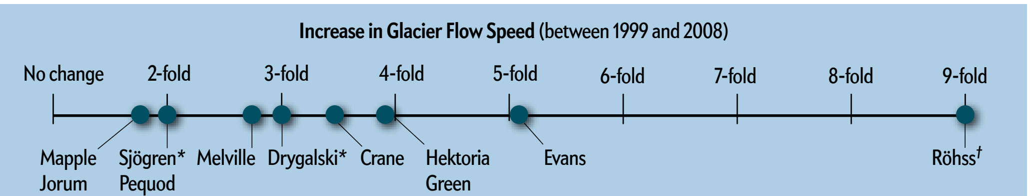


Elevations Change

As glaciers melt, their elevations decrease. Yet some inland regions are rising; warmer temperatures increase ocean evaporation, bringing more snow to the interior and raising the ice pack. Still, glacier loss is far greater than snow gain.

Glaciers Flow

Once an ice shelf collapses, glaciers on land behind it accelerate toward the sea [*see box on next page*]. Although the glaciers surge and slow, their average flow speeds have increased significantly.



*Between 1995 and 1999 †Between 2001 and 2009

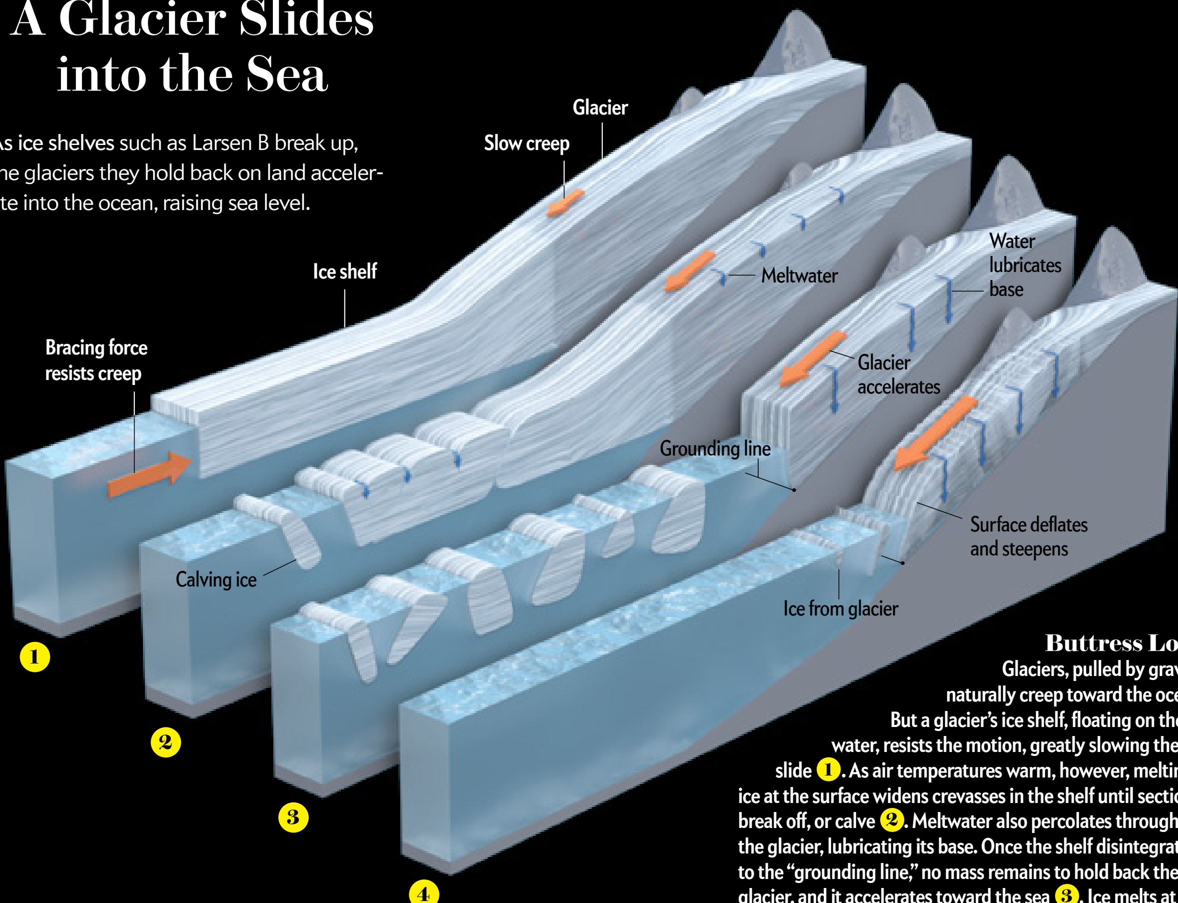
SOURCES: ALISON COOK *Swansea University* (*ice shelf and air temperature data*); HAMISH PRITCHARD *British Antarctica Survey* (*surface elevation map*); "GLACIER SURGE AFTER ICE SHELF COLLAPSE," BY HERNÁN DE ANGELIS AND PEDRO SKVARCA, IN *SCIENCE*, VOL. 299; MARCH 7, 2003 (*Drygalski and Sjögren Glacier speed*); "FROM ICE-SHELF TRIBUTARY TO TIDEWATER GLACIER: CONTINUED RAPID RECESSION, ACCELERATION AND THINNING OF RÖHSS GLACIER FOLLOWING THE 1995 COLLAPSE OF THE PRINCE GUSTAV ICE SHELF, ANTARCTIC PENINSULA," BY N. F. GLASSER ET AL., IN *JOURNAL OF GLACIOLOGY*, VOL. 57, NO. 203; JUNE 2011 (*Röhss Glacier speed*); "THE IMBALANCE OF GLACIERS AFTER DISINTEGRATION OF LARSEN-B ICE SHELF, ANTARCTIC PENINSULA," BY H. ROTT ET AL., IN *CRYOSPHERE*, VOL. 5; 2011 (*other glacier speeds*); CONSULTANT: THEODORE SCAMBOS *National Snow and Ice Data Center*

Map by XNR Productions

SLIPPERY SLOPE

A Glacier Slides into the Sea

As ice shelves such as Larsen B break up, the glaciers they hold back on land accelerate into the ocean, raising sea level.



Buttress Lost

Glaciers, pulled by gravity, naturally creep toward the ocean. But a glacier's ice shelf, floating on the water, resists the motion, greatly slowing the slide **1**. As air temperatures warm, however, melting ice at the surface widens crevasses in the shelf until sections break off, or calve **2**. Meltwater also percolates through the glacier, lubricating its base. Once the shelf disintegrates to the "grounding line," no mass remains to hold back the glacier, and it accelerates toward the sea **3**. Ice melts at an increasing rate; the glacier's lower portion deflates, its slope steepens, and chunks calve from the front edge **4**.

nitude of change," says Robert DeConto, an ice sheet modeler at the University of Massachusetts Amherst. "We're sitting on our hands waiting for data." Researchers on recent expeditions to the frozen continent have planted instruments that are giving scientists the information they need, and the latest projections from those data are alarming.

A HARD BOUNCE OFF ICEBERG UK211

THE FIRST documented disappearance of an Antarctic ice shelf occurred around 25 years ago. The Larsen Inlet ice shelf, a 350-square-kilometer slab north of Larsen A, was present in a satellite photograph taken in 1986, but by the time another image was made in 1988, most of it was missing. No one had any sense of how it might have vanished.

The austral summer of 1995 opened some eyes. Just as Larsen A underwent its now notorious collapse, the Prince Gustav ice shelf, 60 kilometers to the north, also vanished. "The disintegration came as a total surprise," says Scambos, who, with scientists at the British Antarctic Survey, has been monitoring the continent's ice shelves continually via satellite for many years. The effects of these breakups have reverberated throughout the region. In aerial photographs taken before Prince Gustav disappeared, Sjögren Glacier was a smooth-surfaced plume that sloped gradually from the mainland far out into the fjord, inching toward the ice shelf and sea. But 15 years later Sjögren is a sorry sight, wrinkled with crevasses and sagging in the middle. After the Prince Gustav ice shelf disappeared, Sjögren accelerated toward the ocean at several times its former speed. Crevasses 20 meters wide opened across its surface as the 600-meter-thick ice below stretched under the seaward deformation. Enormous icebergs splintered, uncontrolled, off Sjögren's front edge; that edge now sits 15 kilometers farther back into the fjord than it used to.

"Every single glacier that flowed into an ice shelf, when the shelf was removed, suddenly accelerated," Scambos says. "Not just a little bit but by a factor of two, three, five, up to eight times as fast."

Seven summers later, in 2002, the Larsen B ice shelf, just south of Larsen A and 55 times larger than Manhattan, disintegrated into hundreds of shards the size of skyscrapers. "We could see whales in places where the ice was 300 meters thick a few days earlier," says Pedro Skvarca, a glaciologist with the Argentine Antarctic Institute in Buenos Aires who flew over the site in a plane shortly afterward. "We were quite astonished."

Once again, the demise of floating ice removed the backstop

Illustration by Bryan Christie

that stabilized glaciers behind it. As a result of such breakups, more than 150 cubic kilometers of glacial ice has slid off land into the ocean. So great a load has been removed that the earth's crust is literally springing up from below. After Larsen B's collapse, a sensitive GPS instrument bolted into the bedrock on Anvers Island, 150 kilometers west, showed that the rate of tectonic uplift had nearly tripled, from 0.3 to 0.8 centimeter a year.

Healthy ice shelves tend to shed, or "calve," large, tabular icebergs, sometimes larger than the state of Rhode Island. But Larsen B broke up in a very different way. A series of seven sharp images from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument, taken over 35 days, showed Larsen B splintering into hundreds of bergs on the order of 130 meters wide, 160 meters deep and a kilometer or more long. The bergs, shaped like the long, narrow geometric blocks that descend in the game Tetris, rolled off the edge of the ice shelf and into the ocean to reveal their cross sections of blue glacial ice. Researchers had never seen this pattern of calving before. The ice shelves were dying from some heretofore unrecognized mechanism.

Scambos and Skvarca first attempted to understand that mechanism of collapse in March 2006. On a dim, cold day an Argentine naval helicopter landed on a broad, tabular berg with a precarious, sideways bounce; the pilot, thrown off by the berg's uniform milky white color, did not realize that his spinning rotors had dipped dangerously low. Scambos, Skvarca and four other scientists climbed out of the helicopter. This iceberg, named UK211, had survived for three years since calving off the Larsen C ice shelf 385 kilometers south, but now it was drifting into warm climates north of the peninsula. Scambos and the others hoped to use it as an experimental analogue for ice shelf breakup.

The team installed an instrument station, dubbed AMIGOS (Automated Met-Ice Geophysics Observation Systems), that would monitor the berg's deteriorating health. A GPS unit tracked the berg's position, a meteorological station measured wind and temperature, and a camera documented snowmelt on the surface. The camera could be aimed at a marked pole driven into the berg to show how quickly the snow level dropped as the result of melting. The camera could also be aimed at a line of poles that the researchers planted 2.2 kilometers out toward the berg's edge. If that line started to curve, it would indicate that the berg was softening and bending.

Scambos and Skvarca tracked UK211 for eight months, communicating with AMIGOS by satellite phone. The berg, originally 10 by 12 kilometers, slowly shrank by half. Then, on November 23, 2006, AMIGOS phoned home for the final time. A few days later UK211 was gone, sending AMIGOS to the bottom of the sea.

UK211 underwent many changes, but the one that immediately preceded its sudden demise was the melting of snow that transformed the berg's surface into waterlogged slush. The meltwater may have percolated into the berg's interior and destabilized it, Scambos says. But the experiment did not show him the moment of disintegration—only what led up to it. And because UK211 was a free-drifting berg, not an ice shelf, Scambos could not quantify how glaciers feeding into the berg would respond.

SO MUCH ANTARCTIC ICE HAS GONE THAT THE EARTH'S CRUST IS SPRINGING UPWARD.

TRAPPED GLACIOLOGISTS FIND A WAY

THOSE QUESTIONS led Scambos to join a difficult but critical expedition in 2010 to a remnant of Larsen B called the Scar Inlet ice shelf. A laser altimeter onboard the ICESat satellite had documented the thinning of glaciers feeding into Larsen B and Scar Inlet—as indicated by lowering of the ice surface—but the altimeter had fizzled out earlier that year. Interferometric synthetic-aperture radar measurements from other satellites had provided long-term averages of how quickly glaciers behind ice shelves like Scar Inlet were flowing into the sea, but the technique would not capture sudden events like glacier surges. Since 2003 the GRACE satellites had measured ice loss through variations in the earth's gravitation but only at the fuzzy resolution of hundreds of kilometers.

Scambos expected the Scar Inlet ice shelf to collapse within a few years, and he wanted to plant an array of sensors on the ground there to capture the cataclysm. "We want to watch this process from the very beginning and in greater detail than what we've seen from satellites," he told me in 2010, as we sat indoors on the *Nathaniel B. Palmer,* a 6,000-metric-ton icebreaker that serves the U.S. Antarctic Program. "We want to see the big show at the end."

For 57 days in January and February 2010, the *Palmer* plowed along the peninsula toward Scar Inlet, ramming through seasonal sea ice up to two meters thick. Scambos and two dozen scientists onboard had hoped to get close enough to fill in critical blind spots in their knowledge. They ran into trouble only days into the expedition, however. Severe sea ice, pushed up against the peninsula by ocean currents and winds, prevented the *Palmer* from getting within easy helicopter range of Scar Inlet. So, on January 26, Scambos was dropped off at a British research station with four other glaciologists, including Martin Truffer and Erin Pettit of the University of Alaska Fairbanks. From there a Twin Otter plane delivered them to their first field site. The team spent three weeks hopping by plane between the Scar Inlet ice shelf and the glaciers feeding into it.

On days when snowstorms subsided, the researchers installed AMIGOS on Scar Inlet and on the lower reaches of Flask Glacier (and they plan to install another AMIGOS on the lower Leppard Glacier in 2013). Higher up on Flask and Leppard, they installed simpler meteorological and GPS stations. On a coastal bluff overlooking Scar Inlet, they mounted a steerable camera.

Scambos's team members encountered unexpected conditions on the Scar Inlet ice shelf. When they dug in and around camp, their shovels plunged into empty voids—crevasses in the ice veiled under thin crusts of snow. One day the plane's pilot sunk up to his waist in another hidden crevasse. Those cracks may have previously been buried under thicker snow, but hot summers had melted it away, bringing the cracks to the surface—just as Brückner and his Argentine soldiers had seen in the last days of Larsen A.

One summer soon the Scar Inlet ice shelf will cross a critical threshold. Repeated cycles of melting and refreezing will harden its surface until it can hold large melt ponds. Those ponds will drain into exposed crevasses. As water accumulates in crevasses, its weight will drive the cracks deeper—"like a wedge," Scambos says—until they reach the bottom of the ice, breaking off a long, skinny Tetris berg. The rupture of one crevasse will produce shock waves that will set off others closer to land's edge. The entire ice shelf might disintegrate within only a few days—maybe just hours.

That is how Scambos thinks Scar Inlet will die. The AMIGOS will let him test the theory. Their cameras will show melt ponds forming, crevasses opening and ponds draining into them. Shots of the pole lines will show the ice shelf straining and buckling. The ridgetop camera will record the pattern of iceberg calving. The AMIGOS on Flask and Leppard will show how the glaciers speed up as the ice shelf holding them back collapses. By having upstream and downstream stations on each glacier, Scambos will see the dynamic nature of glacial response—the manner in which the bottom of the glacier accelerates before its higher reaches do, thus causing it to stretch, thin and welt up with crevasses the way Sjögren Glacier did. The Scar Inlet ice shelf, Scambos says, "is teetering on the edge."

ROCK, DATA, SCISSORS

GLACIERS on the Antarctic Peninsula that have lost their ice shelves are indeed thinning at a rapid rate of five to 10 meters a year. The data come from laser altimetry measurements that were taken by the now defunct ICESat and, more recently, by aircraft. The crucial question is how this rate compares with the gradual thinning that has happened since the close of the last ice age 12,000 years ago—and in particular, whether the recent ice shelf breakups are truly unprecedented. Greg Balco, a geologist at the Berkeley Geochronology Center who was on the *Palmer,* wanted to answer this question.

On a cold, overcast morning a helicopter ferried Balco and me from the *Palmer* to Sjögren Glacier, 30 kilometers west. Sjögren's fjord held ice 600 meters thick as recently as 1995, right before the Prince Gustav ice shelf broke up, but now it holds seawater instead.

The helicopter dropped us on a bare, rounded mountain beside the fjord. The peak's gray-and-white-layered bedrock was worn into smooth curves and was raked with scrape marks—scars that a younger, thicker Sjögren Glacier left as it rode over this terrain thousands of years ago. "This is beautifully polished," Balco said of the bedrock. "It looks like it deglaciated last week." Scattered all around were stones that did not match the bedrock—a brown volcanic boulder here, granite over there. Sjögren had carried them in from far away and dropped them in their present locations as its ice melted.

Balco used these oddball rocks to figure out how quickly Sjögren Glacier has thinned over thousands of years. He picked his way uphill, collecting rocks at different elevations. Back home, he analyzed them to see how long they had been exposed to sunlight by measuring tiny amounts of a rare isotope called beryllium 10, which forms when cosmic rays strike stone. By measuring how long rocks at different heights on the mountain have seen sunlight, Balco could calculate how quickly the glacier thinned and reexposed the mountain.

A year after the expedition Balco had analyzed rocks collected from around two glaciers—Sjögren and Drygalski. His results suggested that the glaciers have undergone major retreats at least once in the past 4,000 years—indicating that both the Prince Gustav and Larsen A ice shelves had collapsed at least once in that time.

Balco never reached Larsen B because of the ship's problems with sea ice, but Eugene Domack, the marine geologist who led the 2010 expedition, has already estimated the age of the Larsen B ice shelf. Domack, an environmental studies professor at Hamilton College, managed to reach the Larsen B area during earlier cruises. His team bored several three-meter-long columns of sediment from parts of the seafloor that were covered by Larsen B until its collapse. Cores taken from under the open ocean are often stained green from microscopic plants called diatoms that settle to the seafloor after dying, but this core contained none. Layer on layer of fine, sandy mud created by grinding glaciers revealed that Larsen B had shaded this area for at least 11,000 years. Layers in the core were dated by analyzing the carbon 14 content of shells left by microscopic organisms called foraminafera.

Eleven thousand years is as far down as Domack's core reached. He says, however, Larsen B may have persisted as far back as 100,000 years, the beginning of the last ice age. Taken together, Balco's and Domack's results suggest that the northernmost ice shelves on the Antarctic Peninsula have come and gone in the recent past. But as the chain of ice shelf collapse pushes farther south from the peninsula's tip toward the mainland, to Larsen B and Scar Inlet, it is now entering the ominous realm of historical anomaly.

SJÖGREN FJORD HELD ICE 600 METERS THICK IN 1995; NOW IT HOLDS WATER.

IMPLOSION, THEN ACCELERATION

EIGHTEEN MONTHS after the *Palmer* returned to port in Punta Arenas, Chile, Scambos reviewed the data streaming in, via satellite, to his office in Boulder. The Scar Inlet ice shelf still has not collapsed—but instruments on the ground had already revealed other insights that were totally unexpected. Researchers had assumed, for example, that even if the peninsula's ice shelves experienced brutal summers, the winters would still nourish them with new snow. Yet when Scambos and his team had returned in November 2010 to repair the station, they found the Scar Inlet ice shelf too crisscrossed with exposed crevasses for their plane to land. As the Twin Otter skimmed overhead, the boot and skid marks that they had left nine months earlier were still visible: a winter that should have nourished Scar Inlet with new snow left it, instead, one step closer to collapse.

Another surprise had occurred that same year between July 14 and 15, during the dark depths of the polar winter. The AMIGOS on Scar Inlet reported a heat wave. The temperature suddenly shot up by 43 degrees Celsius, topping out at a toasty 10 degrees C—shirtsleeve weather in Boulder. The heat was driven by westerly "foehn" winds, which formed as air sliding down the mountains of the peninsula compressed and warmed. At the same time, thermistors buried several meters into the ice at the AMIGOS site recorded a pulse of warmth—suggesting that water from snowmelt was percolating down.

No one knows how often these foehn winds happen—but, Scambos says, "we could be missing some important facts." The average speed of winds blowing off Antarctica's coastlines has in-

DATA DIG: **A helicopter hauls instruments to glaciers that are sliding into the sea (*top*). A long sediment core taken from the Barilari Bay seafloor (*bottom*) could determine when the water had been covered by ice shelves in past centuries.**

creased by 10 to 15 percent over the past 30 years. Wind now scours 50 billion to 150 billion metric tons of snow from Antarctica's surface each year, blowing it into the ocean, where it melts. As winds strengthen, scouring will likely increase, potentially worsening the prognosis for ice shelves in a way no one anticipated.

What is more, three precision GPS units that Domack had bolted into bedrock outcrops around the perimeters of Larsen B and Scar Inlet show that this region is now rising 1.8 centimeters a year. The disappearance of heavy glaciers is allowing the earth's crust below to rebound—"remarkably fast," Domack says, and far greater than the 0.8 centimeter estimated from a GPS station 150 kilometers away. The rate of tectonic uplift will increase again when the Scar Inlet ice shelf implodes and the glaciers behind it surge into the ocean. Measure that uplift, Domack says, and you can estimate the amount of ice spilling out. Do that at Scar Inlet, and you can better predict how much ice will disappear as other ice shelves succumb farther south.

That more ice shelves will collapse is a foregone conclusion. An average summer temperature of zero degrees C seems to represent the highest temperature at which an ice shelf can exist. And the invisible line where summer averages zero degrees C is creeping south along the Antarctic Peninsula tip toward the mainland, along with higher mean annual temperatures. Every ice shelf that the line crosses has collapsed within a decade or so. Next up, south of Larsen B and Scar Inlet, is the Larsen C ice shelf, which covers 49,000 square kilometers—twice as large as the state of Maryland, or about 820 Manhattans. Larsen C has more glacial ice flowing into it than all the other ice shelves that have collapsed combined. It already sees summer melt ponds on its northern end.

Even more worrying are the ice shelves hanging off the mainland, which support much larger glaciers, such as Pine Island, Thwaites and Totten. They are melting from their undersides because of warmer ocean currents, rather than from the top down. The result is the same: Pine Island Glacier has thinned by only 15 percent since 1994, yet the massive glacier behind it has accelerated by 70 percent.

The full effects of ice shelf breakup on glacier demise will not be known for some time. A study published in 2011 by Scambos, Truffer and Pettit found that one glacier continues to accelerate even 15 years after losing its ice shelf: Röhss Glacier (which used to flow into the Prince Gustav ice shelf) has now reached nine times its former speed.

This acceleration in glacier flow may explain a recent observation by Eric Rignot and Isabella Velicogna of the NASA Jet Propulsion Laboratory. They found that the rate of ice loss from Antarctica is actually increasing by roughly 25 cubic kilometers a year. Those 2007 IPCC estimates of 18 to 59 centimeters of sea-level rise by 2100 do not account for any of these ice shelf effects. The estimates "actually send the wrong message," Rignot says. "They're probably off by a factor of two to three." By 2100, he says, "you could easily see a meter of sea-level rise." An analysis published in 2009 by Martin Vermeer of the Helsinki University of Technology places the estimate between 75 and 190 centimeters.

Such hints beg further monitoring of the Larsen region—an area that punishes those who try to pry apart its secrets. Prior to the 2010 *Palmer* expedition Domack had sailed to the area on five earlier research cruises, three of which never reached their geographic target because of brutal sea ice. "It can be really frustrating," he admits. But important questions are bound to keep him and Scambos coming back. ■

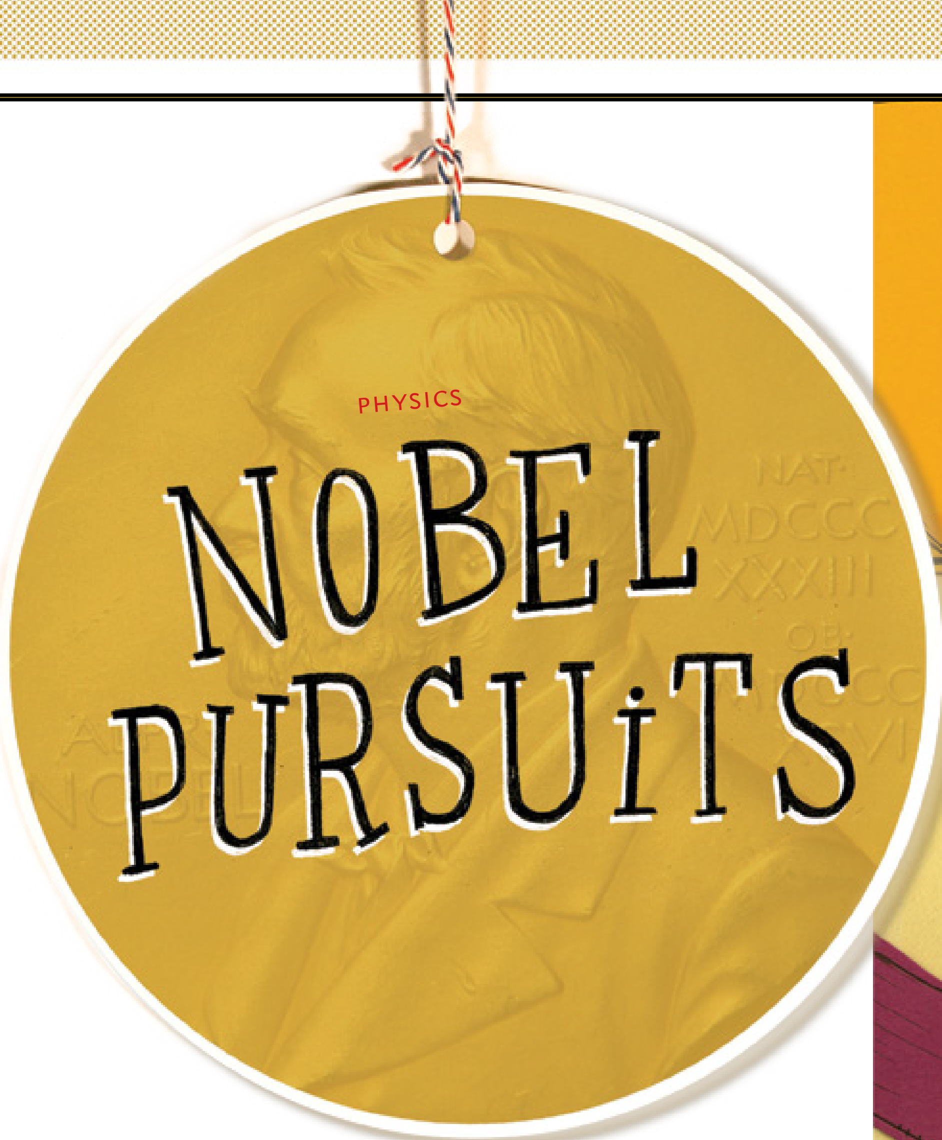
MORE TO EXPLORE

Glacier Surge after Ice Shelf Collapse. Hernán De Angelis and Pedro Skvarca in *Science,* Vol. 299, pages 1560–1562; March 7, 2003.

Stability of the Larsen B Ice Shelf on the Antarctic Peninsula during the Holocene Epoch. Eugene Domack et al. in *Nature,* Vol. 436, pages 681–685; August 4, 2005.

Calving and Ice-Shelf Break-up Processes Investigated by Proxy: Antarctic Tabular Iceberg Evolution during Northward Drift. T. Scambos et al. in *Journal of Glaciology,* Vol. 54, No. 187, pages 579–591; December 2008.

SCIENTIFIC AMERICAN ONLINE
See photographs of scientists doing the glacier and ocean fieldwork described in this article at **ScientificAmerican.com/jul2012/antarctica**



PHYSICS

NOBEL PURSUITS

The tools of science have changed since the golden age of physics, but many of the same questions remain

By John Matson and Ferris Jabr

Illustrations by John Hendrix

EVERY SUMMER NOBEL LAUREATES CONVERGE ON Lindau, Germany, to share their wisdom with, and to learn from, up-and-coming scientists hailing from many corners of the globe. This year the 62nd meeting focuses on physics. In honor of that event, the two of us have selected excerpts from some of the most fascinating articles that Nobel winners have published in the magazine over the years, on topics ranging from cosmology to particle physics to technology.

As we gathered these selections, which begin on the opposite page, we were struck anew by the way the problems that puzzled physicists decades ago continue to drive research today. Yes, the field has changed since the days of Albert Einstein, P.A.M. Dirac and Enrico Fermi. Physicists have made vast leaps (such as constructing and honing the Standard Model of particle physics) and encountered strange turns (such as dark energy). Yet many of the questions being tackled now are the same, at root, as those that have spurred research throughout the past century—among them: Why is matter so much more abundant than antimatter? Does the Higgs boson, widely believed to account for the mass of subatomic particles, truly exist? And what does "spooky action at a distance" betray about the workings of the world?

Matter is everywhere. It makes up this magazine, your hand and even the air between the page and your face. Antimatter, on the other hand, is exceedingly rare. (That is a good thing for us creatures of matter because particles and antiparticles annihilate on contact.) But matter and antimatter should have existed in balance at the dawn of the universe; somehow matter won out to allow the formation of galaxies, solar systems and people. Physicists have long wondered what tipped the scales.

In 1956 Emilio Segrè and Clyde E. Wiegand detailed in the pages of *Scientific American* their team's discovery of the antiproton, the antimatter counterpart to the familiar proton at the heart of every atom. Segrè and Wiegand's group had identified the short-lived antiparticles just the year before at the now defunct Bevatron particle accelerator at the University of California, Berkeley, and Segrè and Owen Chamberlain, his Berkeley colleague, would share the 1959 Nobel Prize in Physics for the discovery. Their detection of antiprotons followed the discovery in 1932 by Carl D. Anderson of antielectrons, or positrons, which itself followed a theoretical description in 1930 of the electron by Dirac, which suggested the existence of such antiparticles.

Physicists have since taken the next logical step in the footsteps of Dirac, Anderson, Chamberlain and Segrè: cobbling together rudimentary atoms of antimatter to see if they differ in some crucial aspect from ordinary atoms. At CERN near Geneva, researchers combine antiprotons with positrons to produce antihydrogen atoms. Last year one group succeeded in protecting the antiatoms from annihilation for several minutes—plenty of time to run tests on the stuff. If gravity or radiation interacts differently with antimatter, that might offer clues to why matter is so much more abundant today.

Exploring another corner of physics, Martinus J. G. Veltman wrote in 1986 in *Scientific American* of a slight problem with the Standard Model, the otherwise spectacularly solid framework that describes the elementary particles of our universe. One key particle within the Standard Model had yet to be observed, Veltman noted, and indeed that particle seemed to be working hard to avoid detection. Without it, the masses of other particles would be difficult to explain.

The particle is, of course, the Higgs boson. More than 25 years after Veltman wrote of the possibility that the Higgs could be discovered at the planned Superconducting Super Collider (SSC) in Texas, physicists still await their first look at the all-important boson. The SSC was never completed, so the chase moved to the Large Hadron Collider (LHC) at CERN, which has been running since 2009. CERN has gradually ramped up the energy of LHC collisions and expects to have enough data by year's end to finally declare whether the Standard Model's Higgs exists.

Even before the Standard Model was pieced together, physicists were picking apart the behaviors of the particles it describes. In 1935 Einstein, along with two colleagues, authored a paper pointing out that quantum mechanics, as formulated at the time, necessitated an uncomfortable phenomenon known as nonlocality. An observer measuring a particle in one location, the physicists noted, could instantaneously affect the state of a particle in another location, however distant. Such an effect seemed absurd. Nonlocality was a problem, Einstein and his colleagues held, that could cast doubt on the viability of quantum mechanics.

It took decades for experimental physicists to verify that particles can indeed share nonlocal connections via a phenomenon known as quantum entanglement. Physicists now routinely produce pairs of entangled photons that share, say, one polarization state between them. Individual atoms have also been entangled, as have macroscopic objects, such as wafers of synthetic diamond. And entanglement is not just a quantum parlor trick—one day it may enable communications and computation vastly more powerful than today's electronics can muster.

The key to those experiments has been the laser, the quantum flashlight whose well-behaved photons can themselves be entangled or can be used to establish entanglement between other particles. In a 1961 article excerpted on page 71, Arthur L. Schawlow touts the considerable promise of the laser, originally known as the optical maser, which at the time was just a year old. Schawlow received a Nobel Prize in 1981 for his role in the laser's invention. His intellectual descendants, those optical physicists who have harnessed the laser to explore quantum entanglement, have often been flagged as front-runners for a Nobel in the near term.

Where will the next generation of Nobel Prize–winning physicists, some of whom may be found at this year's Lindau gathering, lead the field? If history is a guide, some hints of future glory may be found in the prizewinners—and the magazine articles—of decades past.

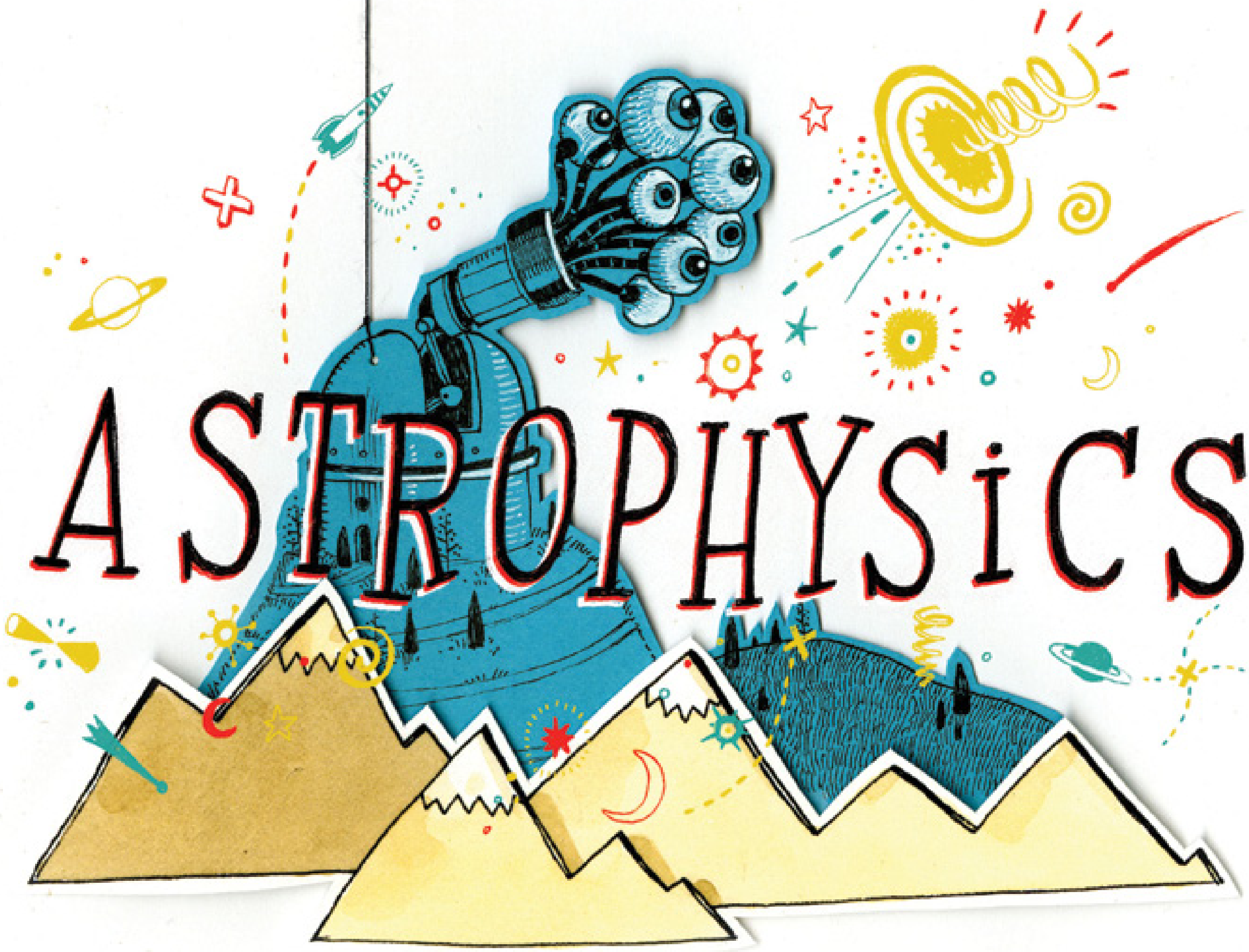
IN BRIEF

An annual gathering in Lindau, Germany, brings together promising early-career scientists and veteran Nobel Prize winners in their field. This year's meeting focuses on physics.

In honor of the Lindau meeting, Scientific American has collected 12 articles from the magazine's archive, excerpted here, written by winners of the Nobel Prize in Physics.

Some of the excerpts recount prize-winning discoveries, some speculate on the future of physics and some address eternal questions: What is the universe made of? And are we alone in it?

Even though some of the articles excerpted here were first published many decades ago, a surprising number remain relevant to the ongoing investigations of modern physicists.



The Secret Message of the Cosmic Ray

By Arthur H. Compton

PUBLISHED IN JULY 1933

NOBEL PRIZE IN 1927

The study of cosmic rays has been described as "unique in modern physics for the minuteness of the phenomena, the delicacy of the observations, the adventurous excursion of the observers, the subtlety of the analyses, and the grandeur of the inferences." These rays are bringing us, we believe, some important message. Perhaps they are telling us how our world has evolved, or perhaps news of the innermost structure of the atomic nucleus. We are now engaged in trying to decode this message.

About five years ago, two German physicists, Bothe and Kolhörster, did an experiment with counting tubes which convinced them that the cosmic rays are electrically charged particles. If this conclusion is correct, it means, however, that there should be a difference in intensity of the rays over different parts of the earth. For the earth acts as a huge magnet, and this huge magnet should deflect the electrified particles as they shoot toward the earth. The effect should be least near the magnetic poles, and greatest near the equator, resulting in an increasing intensity as we go from the equator toward the poles. A series of half a dozen different experiments designed to detect such effects resulted in inconclusive data.

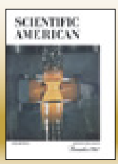
Accordingly, with financial help from the Carnegie Institution, a group of us at the University of Chicago have organized nine different expeditions during the past 18 months, going into different portions of the globe to measure cosmic rays from sea level to the tops of mountains nearly four miles high in the Andes and the Himalayas. Two capable mountaineers, Carpe and Koven, lost their lives on a glacier on the side of mighty Mt. McKinley in Alaska, but they got the highest altitude data yet obtained for latitudes so close to the pole.

On bringing together the results of these expeditions, it was found that the cosmic ray intensity near the poles is about 15 percent greater than near the equator. Furthermore, it varies with latitude, just as predicted, due to the effect of the earth's magnetism on incoming electrified particles. At high altitudes the effect of the earth's magnetism is found to be several times as great as at sea level.

These results show that a considerable part, at least, of the cosmic rays consists of electrified particles. Some of the cosmic rays, however, are not appreciably affected by the earth's magnetic field. Other types of measurements, such as those of Piccard and Regener in their high-altitude balloon flights and Bothe and Kolhörster's counter experiments, lead us to the conclusion that very little of these rays is in the form of photons, like light, but that there is probably a considerable quantity of radiation in the form of atoms or atomic nuclei of low atomic weight.

A word should be said regarding the tremendous energy represented by individual cosmic rays. Let us take as our unit of energy the electron-volt. About two such units are liberated by burning a hydrogen atom. Two million units appear when radium shoots out an alpha particle. But it requires ten thousand million of these units to make a cosmic ray. Where does this tremendous energy come from? In the answer to this question lies perhaps the solution of the riddle as to how our universe came to be.

X-ray Stars



By Riccardo Giacconi

PUBLISHED IN DECEMBER 1967

NOBEL PRIZE IN 2002

Although interstellar space is suffused with radiation over the entire electromagnetic spectrum, from the extremely short waves of gamma rays and X rays to the very long radio waves, relatively little of the cosmic radiation reaches the earth's surface. Our atmosphere screens out most of the wavelengths. In particular the atmosphere is completely opaque to wavelengths shorter than 2,000 angstrom units. Hence X radiation from space can be detected only by sending instruments to the outer regions of our atmosphere in balloons or rockets.

As rocket flights and opportunities to send up instrumented payloads became more frequent, Bruno B. Rossi of the Massachusetts Institute of Technology suggested an X-ray survey of the sky, and a group of us at American Science and Engineering, Inc., undertook the study.

The instrumented Aerobee rocket was launched at the White Sands Missile Range at midnight on June 18, 1962. Our experiment had been prepared by Herbert Gursky, F. R. Paolini and me, with Rossi's collaboration. Some time before the rocket arrived at its peak altitude 225 kilometers (140 miles) above the earth's surface, doors opened to expose the detectors. With the rocket spinning on its axis, the detectors scanned a 120-degree belt of the sky, including the position of the moon.

The telemeter signals from the detectors showed no indication of any X radiation coming from the moon. From the direction of the constellation Scorpio in the southern sky, however, the detectors revealed the presence of an intense source of X rays. The intensity registered by the counters was a million times greater than one would expect (on the basis of the sun's rate of X-ray emission) to arrive from any distant cosmic source!

Three months of close study of the records verified that the radiation was indeed X rays (two to eight angstroms in wavelength), that it came from outside the solar system and that the source was roughly in the direction of the center of our galaxy. What kind of object could be emitting such a powerful flux of X rays?

We made two additional rocket surveys at different times of the year (in October, 1962, and June, 1963) that narrowed down the location of the strong X-ray source by triangulation, and we found that it was not actually in the galactic center. Meanwhile Herbert Friedman and his collaborators at the Naval Research Laboratory succeeded in locating the position of the source within a two-degree arc in the sky, which suggested that the X-ray emitter was a single star rather than a large collection of them.

By this time the evidence that the source was a discrete object had become so strong that we named it Sco (for Scorpius) X-1. One might have expected that an object pouring out so much energy in X radiation would be distinctly visible as at least a rather bright star. The region of the source was barren, however, of conspicuous stars.

The problem then was to identify the X-ray star among the visible stars at the indicated location. The position of Sco X-1 was known only within about one degree, and in its region of the sky there are about 100 13th-magnitude stars in each square degree. A detailed analysis of the new data was made to pinpoint the position more closely. This analysis narrowed the location to two equally probable positions where the star might be found.

Given these positions, the Tokyo Astronomical Observatory and the Mount Wilson and Palomar Observatories made a telescopic search for Sco X-1. The Tokyo astronomers found the X-ray star immediately, and within a week the Palomar observers confirmed the identification.

Now that Sco X-1 can be examined with optical telescopes, it is beginning to yield some striking new information. The most provocative fact is that this star emits 1,000 times more energy in X rays than in visible light, a situation astronomers had never anticipated from their studies of the many varieties of known stars. There are indications that the X-ray emission of Sco X-1 is equal to the total energy output of the sun at all wavelengths.

How a Supernova Explodes

By Hans A. Bethe and Gerald Brown

PUBLISHED IN MAY 1985

NOBEL PRIZE IN 1967 (BETHE)

A supernova begins as a collapse, or implosion; how does it come about, then, that a major part of the star's mass is expelled? At some point the inward movement of stellar material must be stopped and reversed; an implosion must be transformed into an explosion.

Through a combination of computer simulation and theoretical analysis a coherent view of the supernova mechanism is beginning to emerge. It appears the crucial event in the turnaround is the formation of a shock wave that travels outward.

When the center of the core reaches nuclear density, it is brought to rest with a jolt. This gives rise to sound waves that propagate back through the medium of the core, rather like the vibrations in the handle of a hammer when it strikes an anvil. The waves slow as they move out through the homologous core, both because the local speed of sound declines and because they are moving

Cosmic rays are bringing us, we believe, some important message. —ARTHUR H. COMPTON, 1933

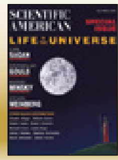
upstream against a flow that gets steadily faster. At the sonic point they stop entirely. Meanwhile additional material is falling onto the hard sphere of nuclear matter in the center, generating more waves. For a fraction of a millisecond the waves collect at the sonic point, building up pressure there. The bump in pressure slows the material falling through the sonic point, creating a discontinuity in velocity. Such a discontinuous change in velocity constitutes a shock wave.

At the surface of the hard sphere in the heart of the star infalling material stops suddenly but not instantaneously. Momentum carries the collapse beyond the point of equilibrium, compressing the central core to a density even higher than that of an atomic nucleus. We call this point the instant of "maximum scrunch." After the maximum scrunch the sphere of nuclear matter bounces back, like a rubber ball that has been compressed. The bounce sets off still more sound waves, which join the growing shock wave.

A shock wave differs from a sound wave in two respects. First, a sound wave causes no permanent change in its medium; when the wave has passed, the material is restored to its former state. The passage of a shock wave can induce large changes in density, pressure and entropy. Second, a sound wave—by definition—moves at the speed of sound. A shock wave moves faster, at a speed determined by the energy of the wave. Hence once the pressure discontinuity at the sonic point has built up into a shock wave, it is no longer pinned in place by the infalling matter. The wave can continue outward, into the overlying strata of the star. According to computer simulations, it does so with great speed, between 30,000 and 50,000 kilometers per second.

After the outer layers of a star have been blown off, the fate of the core remains to be decided. The explosion of lighter stars presumably leaves behind a stable neutron star. In Wilson's calculations any star of more than about 20 solar masses leaves a compact remnant of more than two solar masses. It would appear that the remnant will become a black hole, a region of space where matter has been crushed to infinite density.

Life in the Universe



By Steven Weinberg

PUBLISHED IN OCTOBER 1994

NOBEL PRIZE IN 1979

Life as we know it would be impossible if any one of several physical quantities had slightly different values. The best known of these quantities is the energy of one of the excited states of the carbon 12 nucleus. There is an essential step in the chain of nuclear reactions that build up heavy elements in stars. In this step, two helium nuclei join together to form the unstable nucleus of beryllium 8, which sometimes before fissioning absorbs another helium nucleus, forming carbon 12 in this excited state. The carbon 12 nucleus then emits a photon and decays into the stable state of lowest energy. In subsequent nuclear reactions carbon is built up into oxygen and nitrogen and the other heavy elements necessary for life. But the capture of helium by beryllium 8 is a resonant process, whose reaction rate is a sharply peaked function of the energies of the nuclei involved. If the energy of the excited state of carbon 12 were just a little higher, the rate of its formation would be much less, so that almost all the beryllium 8 nuclei would fission into helium nuclei before carbon could be formed. The universe would then consist almost entirely of hydrogen and helium, without the ingredients for life.

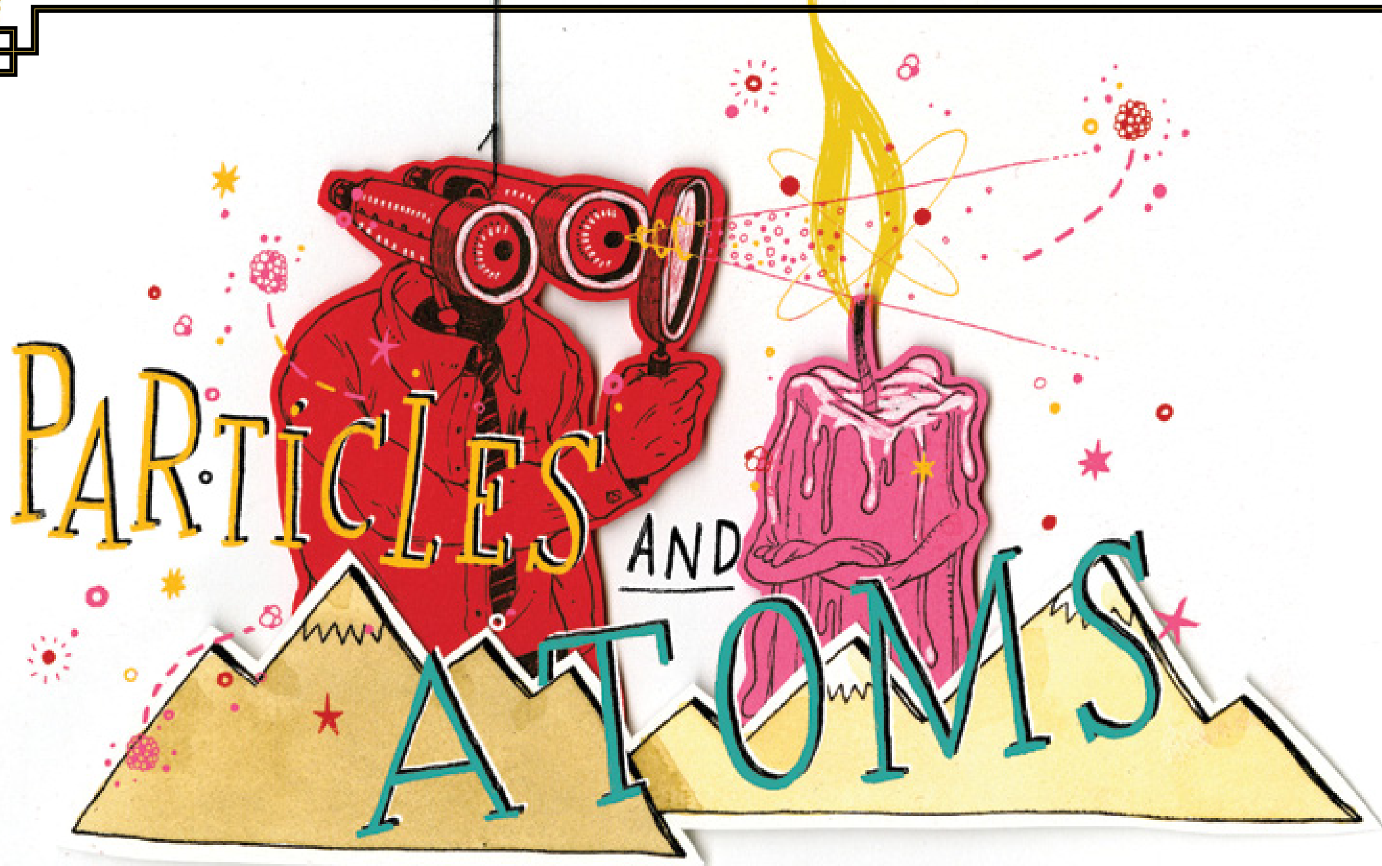
Opinions differ as to the degree to which the constants of nature must be fine-tuned to make life necessary. There are independent reasons to expect an excited state of carbon 12 near the resonant energy. But one constant does seem to require an incredible fine-tuning: it is the vacuum energy, or cosmological constant, mentioned in connection with inflationary cosmologies.

Although we cannot calculate this quantity, we can calculate some contributions to it (such as the energy of quantum fluctuations in the gravitational field that have wavelengths no shorter than about 10^{-33} centimeter). These contributions come out about 120 orders of magnitude larger than the maximum value allowed by our observations of the present rate of cosmic expansion. If the various contributions to the vacuum energy did not nearly cancel, then, depending on the value of the total vacuum energy, the universe either would go through a complete cycle of expansion and contraction before life could arise or would expand so rapidly that no galaxies or stars could form.

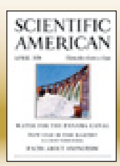
Thus, the existence of life of any kind seems to require a cancellation between different contributions to the vacuum energy, accurate to about 120 decimal places. It is possible that this cancellation will be explained in terms of some future theory. So far, in string theory as well as in quantum field theory, the vacuum energy involves arbitrary constants, which must be carefully adjusted to make the total vacuum energy small enough for life to be possible.

All these problems can be solved without supposing that life or consciousness plays any special role in the fundamental laws of nature or initial conditions. It may be that what we now call the constants of nature actually vary from one part of the universe to another. (Here "different parts of the universe" could be understood in various senses. The phrase could, for example, refer to different local expansions arising from episodes of inflation in which the fields pervading the universe took different values or else to the different quantum-mechanical "worldtracks" that arise in some versions of quantum cosmology.) If this were the case, then it would not be surprising to find that life is possible in some parts of the universe, though perhaps not in most.

Naturally, any living beings who evolve to the point where they can measure the constants of nature will always find that these constants have values that allow life to exist. The constants have other values in other parts of the universe, but there is no one there to measure them. Still, this presumption would not indicate any special role for life in the fundamental laws, any more than the fact that the sun has a planet on which life is possible indicates that life played a role in the origin of the solar system.



What Is Light?



By Ernest O. Lawrence and J. W. Beams

PUBLISHED IN APRIL 1928

NOBEL PRIZE IN 1939 (LAWRENCE)

Light is one of the most familiar physical realities. All of us are acquainted with a large number of its properties, while some of us who are physicists know a great many more marvelous characteristics which it displays. The sum total of our knowledge of the physical effects produced by light is very considerable, and yet we have no satisfactory conception of what it is.

More than two centuries ago Newton conceived that light was corpuscular in nature; he believed that light consisted of little darts shooting through space. Others regarded light as a wave phenomenon; in a manner analogous to the propagation of waves in water, light waves were propagated in a medium pervading all space, called the ether. A lively controversy ensued between the adherents of these two conceptions of the nature of light, and as new experiments were carried out revealing more of its properties, it appeared that the undulatory theory accounted for many things quite unintelligible on the corpuscular hypothesis.

As time has progressed, many additional phenomena concerned with the interaction of light and matter have been discovered which are impossible of understanding on the wave theory and which have compelled scientists to revert to the conception of light which was in Newton's mind centuries ago. Such recent facts of observation suggest that light beams contain amounts of energy which are exact multiples of a definite smallest amount—a light quantum—just as matter seems to be made up of definite multiples of a smallest particle of matter or electricity—the electron. Thus, we have atomicity of light as well as atomicity of matter and electricity.

A seemingly very peculiar circumstance exists in this modern quantum theory of light, for the very thing concerned in the theory is entirely obscure.

And so the question of the physical nature of quanta presents itself. Are they a yard or a mile or an inch in length, or are they of infinitesimal dimensions? Many experimental facts can be interpreted as indicating that quanta are at least a yard in length, yet nothing really certain can be inferred from past observations. The dimensions in space of the quanta remain complete mysteries.

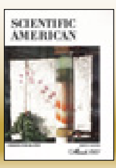
There is at least one way of measuring the length of quanta, provided that the scheme may be carried out in practice, which is essentially as follows: Suppose one had a light shutter that could obstruct or let pass a beam of light as quickly as desired. Such an apparatus would be able to cut up a beam of light into segments, much in the same way that a meat cutter slices a bologna sausage. It is clear that if the slices of the light beam so produced were shorter than the light quanta in the beam, the short light flashes coming from the shutter would contain only parts of quanta. In effect, the apparatus would be cutting off the heads or tails of quanta. To eject an electron from a metal surface a whole quantum is necessary because part of one quantum does not contain enough energy to do the trick. One therefore would definitely establish an upper limit to the length of light quanta by simply observing the shortest light flashes able to produce a photo-electric effect.

One does not have to be very familiar with mechanical things to realize that no mechanical shutter could possibly work at this speed. Happily, however, Nature has endowed matter with properties other than purely mechanical ones. By making use of a certain electro-optical property of some liquids a device was conceived which actually operated as a shutter, turning on and off in about one ten thousand millionth of a second.

The short flashes of light produced in this way were allowed to fall on a sensitive photo-electric cell, and it was found that the cell responded to the shortest flashes obtained—which were only a few feet in length.

The importance of this simple experimental observation cannot be overestimated, for it definitely demonstrated that light quanta are less than a few feet in length and probably occupy only very minute regions of space.

The Structure of the Nucleus



By Maria G. Mayer

PUBLISHED IN MARCH 1951

NOBEL PRIZE IN 1963

For the atom as a whole modern physicists have developed a useful model based on our planetary system: it consists of a central nucleus, corresponding to the sun, and satellite electrons revolving around it, like planets, in certain orbits. This model, although it leaves many questions still unanswered, has been helpful in accounting for much of the observed behavior of the electrons. The nucleus itself, however, is very poorly understood. Even the question of how the particles of the nucleus are held together has not received a satisfactory answer.

Recently several physicists, including the author, have independently suggested a very simple model for the nucleus. It pictures the nucleus as having a shell structure like that of the atom as a whole, with the nuclear protons and neutrons grouped in certain orbits, or shells, like those in which the satellite electrons are bound to the atom. This model is capable of explaining a surprisingly large number of the known facts about the composition of nuclei and the behavior of their particles.

It is possible to discern some rather remarkable patterns in the properties of particular combinations of protons and neutrons, and it is these patterns that suggest our shell model for the nucleus. One of these remarkable coincidences is the fact that the nuclear particles, like electrons, favor certain "magic numbers."

Every nucleus (except hydrogen, which consists of but one proton) is characterized by two numbers: the number of protons and the number of neutrons. The sum of the two is the atomic weight of the nucleus. The number of protons determines the nature of the atom; thus a nucleus with two protons is always helium, one with three protons is lithium, and so on. A given number of protons may, however, be combined with varying numbers of neutrons, forming several isotopes of the same element. Now it is a very interesting fact that protons and neutrons favor even-numbered combinations; in other words, both protons and neutrons, like electrons, show a strong tendency to pair. In the entire list of some 1,000 isotopes of the known elements, there are no more than six stable nuclei made up of an odd number of protons and an odd number of neutrons.

Moreover, certain even-numbered aggregations of protons or neutrons are particularly stable. One of these magic numbers is 2. The helium nucleus, with 2 protons and 2 neutrons, is one of the most stable nuclei known. The next magic number is 8, representing oxygen, whose common isotope has 8 protons and 8 neutrons and is remarkably stable. The next magic number is 20, that of calcium.

The list of magic numbers is: 2, 8, 20, 28, 50, 82 and 126. Nuclei with these numbers of protons or neutrons have unusual stability. It is tempting to assume that these magic numbers represent closed shells in the nucleus, like the electronic shells in the outer part of the atom.

The shell model can explain other features of nuclear behavior, including the phenomenon known as isomerism, which is the existence of long-lived excited states in nuclei. Perhaps the most important application of the model is in the study of beta-decay, i.e., emission of an electron by a nucleus. The lifetime of a nucleus that is capable of emitting an electron depends on the change of spin it must undergo to release the electron. Present theories of beta-decay are not in a very satisfactory state, and it is not easy to check on these theories because only in a few cases are the states of radioactive nuclei known. The shell model can help in this situation, for it is capable of predicting spins in cases in which they have not been measured. Certainly the simple model described here falls short of giving a complete and exact description of the structure of the nucleus. Nonetheless, the success of the model in describing so many features of nuclei indicates that it is not a bad approximation of the truth.

The Antiproton

By Emilio Segrè and Clyde E. Wiegand

PUBLISHED IN JUNE 1956

NOBEL PRIZE IN 1959 (SEGRÈ)

A quarter of a century ago P.A.M. Dirac of the University of Cambridge developed an equation, based on the most general principles of relativity and quantum mechanics, which described in a quantitative way various properties of the electron. He had to put in only the charge and mass of the electron—and then its spin, its associated magnetic moment and its behavior in the hydrogen atom followed with mathematical necessity. Its discoverer found, however, that the equation required the existence of both positive and negative electrons: that is, it described not only the known negative electron but also an exactly symmetrical particle which was identical with the electron in every way except that its charge was positive instead of negative.

A few years after Dirac's prediction, Carl D. Anderson of the California Institute of Technology found positive electrons (positrons) among the particles produced by cosmic rays in a cloud chamber. This discovery set physicists off on a new and more formidable search for another hypothetical particle—a search which was finally rewarded only a few months ago.

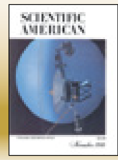
Dirac's general equation, slightly modified, should be applicable to the proton as well as to the electron. In this instance too it predicts the existence of an antiparticle—an antiproton identical to the proton but with a negative instead of a positive charge.

The question then arose as to how much energy would be needed to create antiprotons in the laboratory with an accelerator. Because an antiproton can be created only in a pair with a proton, we need at least the energy equivalent to the mass of two protons (i.e., about two billion electron volts). However, we need much more than two Bev in the proposed laboratory experiment. To convert energy into particles we must concentrate the energy at a point; this is best accomplished by hurling a high-energy particle at a target—e.g., a proton against a proton. After the collision we shall have four particles: the two original protons plus the newly created proton-antiproton pair. Each of the four will emerge from the collision with a kinetic energy amounting to about one Bev. Thus the generation of an antiproton takes two Bev (creation of the proton-antiproton pair) plus four Bev (the kinetic energy of the four emerging particles). It was with these numbers in mind that the Bevatron at the University of California was designed.

When the Bevatron began to bombard a target made of copper with six-Bev protons, the next problem was to detect and identify any antiprotons created. A plan for the search was devised by Owen Chamberlain, Thomas Ypsilantis and the authors of this article. The plan was based on three properties which could conveniently be determined. First, the stability of the particle meant that it should live long enough to pass through a long apparatus. Second, its negative charge could be identified by the direction of deflection of the particle by an applied magnetic field, and the magnitude of its charge could be gauged by the amount of ionization it produced along its path. Third, its mass could be calculated from the curve of its trajectory in a given magnetic field if its velocity was known.

When the discovery of the antiproton was announced last October, 60 of them had been recorded, at an average rate of about four to each hour of operation of the Bevatron. They had passed all the tests which we had preordained before the start of the experiment. We were quite gratified by the comment of a highly esteemed colleague who had just finished an important and difficult experiment on mesons. After examining our tests, he said, "I wish that my own experiments on mu mesons were as convincing as this." At this time several long-standing bets on the existence of the antiproton started to be paid. The largest we know of was for $500. (We were not personally involved.)

The Higgs Boson



By Martinus J. G. Veltman

PUBLISHED IN NOVEMBER 1986

NOBEL PRIZE IN 1999

The Higgs boson, which is named after Peter W. Higgs of the University of Edinburgh, is the chief missing ingredient in what is now called the standard model of elementary processes: the prevailing theory that describes the basic constituents of matter and the fundamental forces by which they interact. According to the standard model, all matter is made up of quarks and leptons, which interact with one another through four forces: gravity, electromagnetism, the weak force and the strong force. The strong force, for instance, binds quarks together to make protons and neutrons, and the residual strong force binds protons and neutrons together into nuclei. The electromagnetic force binds nuclei and electrons, which are one kind of lepton, into atoms, and the residual electromagnetic force binds atoms into molecules. The weak force is responsible for certain kinds of nuclear decay. The influence of the weak force and the strong force extends only over a short range, no larger than the radius of an atomic nucleus; gravity and electromagnetism have an unlimited range and are therefore the most familiar of the forces.

In spite of all that is known about the standard model, there are reasons to think it is incomplete. That is where the Higgs boson comes in. Specifically, it is held that the Higgs boson gives mathematical consistency to the standard model, making it applicable to energy ranges beyond the capabilities of the current generation of particle accelerators but that may soon be reached by future accelerators. Moreover, the Higgs boson is thought to generate the masses of all the fundamental particles; in a manner of speaking, particles "eat" the Higgs boson to gain weight.

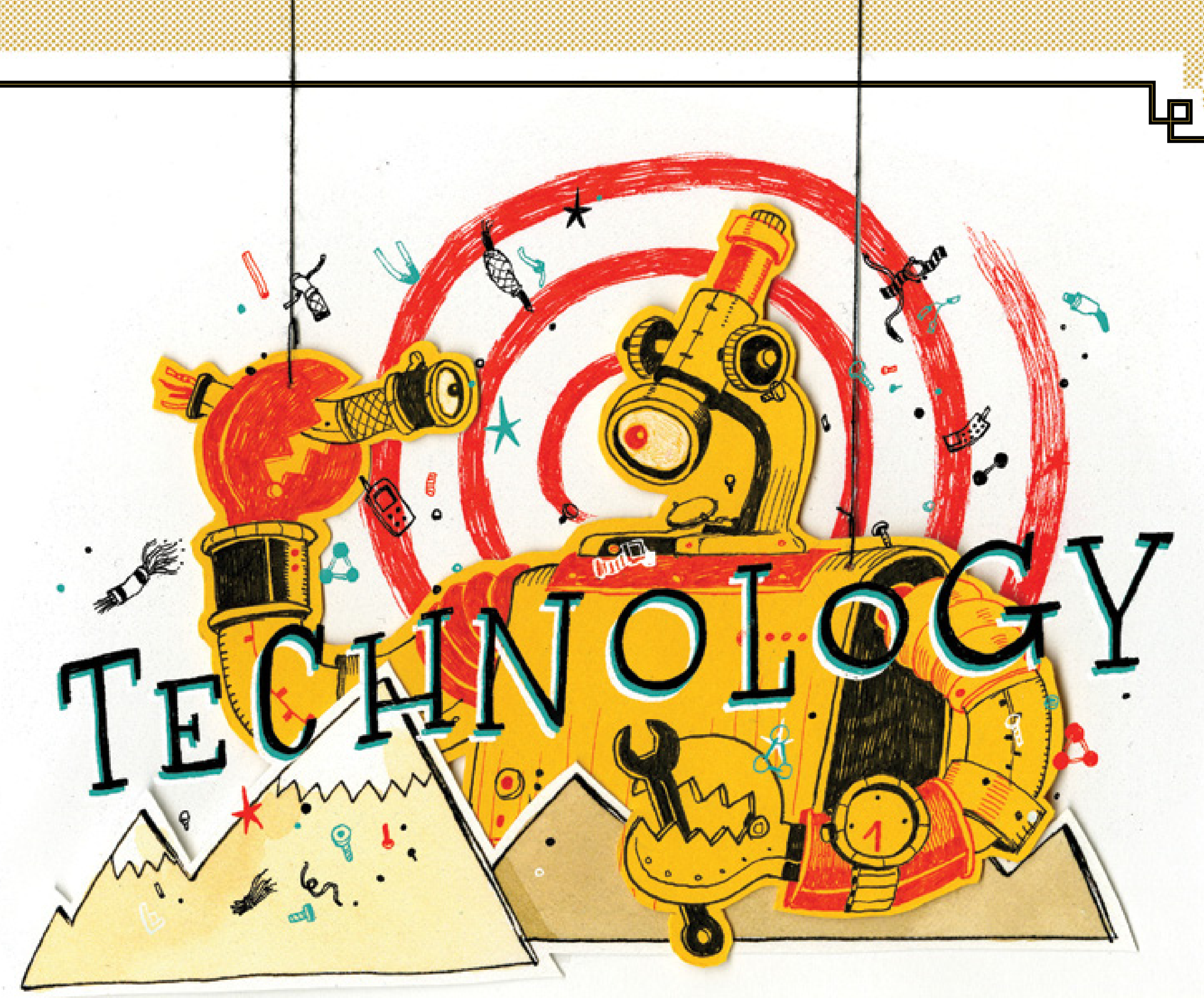
The biggest drawback of the Higgs boson is that so far no evidence of its existence has been found. Instead a fair amount of indirect evidence already suggests that the elusive particle does not exist. Indeed, modern theoretical physics is constantly filling the vacuum with so many contraptions such as the Higgs boson that it is amazing a person can even see the stars on a clear night! Although future accelerators may well find direct evidence of the Higgs boson and show that the motivations for postulating its existence are correct, I believe things will not be so simple. I must point out that this does not mean the entire standard model is wrong. Rather, the standard model is probably only an approximation—albeit a good one—of reality.

Forces among elementary particles are investigated in high-energy-physics laboratories by means of scattering experiments. A beam of electrons might, for instance, be scattered off a proton. By analyzing the scattering pattern of the incident particles, knowledge of the forces can be gleaned.

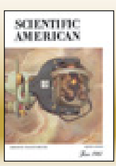
The electroweak theory successfully predicts the scattering pattern when electrons interact with protons. It also successfully predicts the interactions of electrons with photons, with W bosons [particles that make the weak field felt] and with particles called neutrinos. The theory runs into trouble, however, when it tries to predict the interaction of W bosons with one another. In particular, the theory indicates that at sufficiently high energies the probability of scattering one W boson off another W boson is greater than 1. Such a result is clearly nonsense. The statement is analogous to saying that even if a dart thrower is aiming in the opposite direction from a target, he or she will still score a bull's-eye.

It is here that the Higgs boson enters as a savior. The Higgs boson couples with the W bosons in such a way that the probability of scattering falls within allowable bounds: a certain fixed value between 0 and 1. In other words, incorporating the Higgs boson in the electroweak theory "subtracts off" the bad behavior.

Armed with the insight that the Higgs boson is necessary to make the electroweak theory renormalizable, it is easy to see how the search for the elusive particle should proceed: [W bosons] must be scattered off one another at extremely high energies, at or above one trillion electron volts (TeV). The necessary energies could be achieved at the proposed 20-TeV Superconducting Super Collider (SSC), which is currently under consideration in the U.S. If the pattern of the scattered particles follows the predictions of the renormalized electroweak theory, then there must be a compensating force, for which the Higgs boson would be the obvious candidate. If the pattern does not follow the prediction, then the [W bosons] would most likely be interacting through a strong force, and an entire new area of physics would be opened up.



Optical Masers



By Arthur L. Schawlow

PUBLISHED IN JUNE 1961

NOBEL PRIZE IN 1981

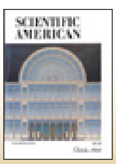
For at least half a century communications engineers have dreamed of having a device that would generate light waves as efficiently and precisely as radio waves can be generated. The contrast in purity between the electromagnetic waves emitted by an ordinary incandescent lamp and those emitted by a radio-wave generator could scarcely be greater. Radio waves from an electromagnetic oscillator are confined to a fairly narrow region of the electromagnetic spectrum and are so free from "noise" that they can be used for carrying signals. In contrast, all conventional light sources are essentially noise generators that are unsuited for anything more than the crudest signaling purposes. It is only within the last year, with the advent of the optical maser, that it has been possible to attain precise control of the generation of light waves.

Although optical masers are still very new, they have already provided enormously intense and sharply directed beams of light. These beams are much more monochromatic than those from other light sources.

The optical maser is such a radically new kind of light source that it taxes the imagination to canvass its possible applications. Message-carrying, of course, is the most obvious use and the one that is receiving the most technological attention. Signaling with light, although it has been used by men since ancient times, has been limited by the weakness and noisiness of available light sources. An ordinary light beam can be compared to a pure, smooth carrier wave that has already been modulated with noise by short bursts of light randomly emitted by the individual atoms in the light source. The maser, on the other hand, can provide an almost ideally smooth wave, carrying nothing but what one puts on it.

If suitable methods of modulation can be found, coherent light waves should be able to carry an enormous volume of information. This is so because the frequency of light is so high that even a very narrow band of the visible spectrum includes an enormous number of cycles per second; the amount of information that can be transmitted is directly proportional to the number of cycles per second and therefore to the width of the band. In television transmission the carrier wave carries a signal that produces an effective bandwidth of four megacycles. A single maser beam might reasonably carry a signal with a frequency, or bandwidth, of 100,000 megacycles, assuming a way could be found to generate such a signal. A signal of this frequency could carry as much information as all the radiocommunication channels now in existence. It must be admitted that no light beam will penetrate fog, rain or snow very well. Therefore to be useful in earthbound communication systems light beams will have to be enclosed in pipes.

Space-Based Ballistic-Missile Defense



By Hans A. Bethe, Richard L. Garwin, Kurt Gottfried and Henry W. Kendall

PUBLISHED IN OCTOBER 1984

NOBEL PRIZE IN 1967 (BETHE) AND IN 1990 (KENDALL)

In his televised speech last year calling on the nation's scientific community "to give us the means of rendering these nuclear weapons impotent and obsolete" the president [Ronald Reagan] expressed the hope that a technological revolution would enable the U.S. to "intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies."

Can any system for ballistic-missile defense eliminate the threat of nuclear annihilation?

Our analysis of the prospects for a space-based defensive system against ballistic-missile attack will focus on the problem of boost-phase interception.

The boost-phase layer of the defense would require many components that are not weapons in themselves. They would provide early warning of an attack by sensing the boosters' exhaust plumes; ascertain the precise number of the attacking missiles and, if possible, their identities; determine the trajectories of the missiles and get a fix on them; assign, aim and fire the defensive weapons; assess whether or not interception was successful; and, if time allowed, fire additional rounds.

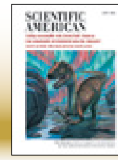
Because the boosters would have to be attacked while they could not yet be seen from any point on the earth's surface accessible to the defense, the defensive system would have to initiate boost-phase interception from a point in space, at a range measured in thousands of kilometers. Two types of "directed energy" weapon are currently under investigation for this purpose: one type based on the use of laser beams, which travel at the speed of light (300,000 kilometers per second), and the other based on the use of particle beams, which are almost as fast. Nonexplosive projectiles that home in on the booster's infrared signal have also been proposed.

Other interception schemes proposed for ballistic-missile defense include chemical-laser weapons, neutral-particle-beam weapons and nonexplosive homing vehicles, all of which would have to be stationed in low orbits.

The brightest laser beam attained so far is an infrared beam produced by a chemical laser that utilizes hydrogen fluoride. The U.S. Department of Defense plans to demonstrate a two-megawatt version of this laser by 1987. Assuming that 25-megawatt hydrogen fluoride lasers and optically perfect 10-meter mirrors eventually become available, a weapon with a "kill radius" of 3,000 kilometers would be at hand. A total of 300 such lasers in low orbits could destroy 1,400 ICBM boosters in the absence of countermeasures if every component worked to its theoretical limit.

A particle-beam weapon could fire a stream of energetic charged particles that could penetrate deep into a missile and disrupt the semiconductors in its guidance system. A charged-particle beam, however, would be bent by the earth's magnetic field and therefore could not be aimed accurately at distant targets. Hence any plausible particle-beam weapon would have to produce a neutral beam. Furthermore, by using gallium arsenide semiconductors, which are about 1,000 times more resistant to radiation damage than silicon semiconductors, it would be possible to protect the missiles' guidance computer from such a weapon.

Accurate Measurement of Time



By Wayne M. Itano and Norman F. Ramsey

PUBLISHED IN JULY 1993

NOBEL PRIZE IN 1989 (RAMSEY)

New technologies, relying on the trapping and cooling of atoms and ions, offer every reason to believe that clocks can be 1,000 times more precise than existing ones.

One of the most promising depends on the resonance frequency of trapped, electrically charged ions. Trapped ions can be suspended in a vacuum so that they are almost perfectly isolated from disturbing influences. Hence, they do not suffer collisions with other particles or with the walls of the chamber.

Two different types of traps are used. In a Penning trap, a combination of static, nonuniform electric fields and a static, uniform magnetic field holds the ions. In a radio frequency trap (often called a Paul trap), an oscillating, nonuniform electric field does the job. Workers at Hewlett-Packard, the Jet Propulsion Laboratory in Pasadena, Calif., and elsewhere have fabricated experimental standard devices using Paul traps. The particles trapped were mercury 199 ions. The maximum Qs [a measure of relative energy absorption and loss] of trapped-ion standards exceed 10^{12}. This value is 10,000 times greater than that for current cesium beam clocks [the higher the Q, the more stable the clock].

During the past few years, there have been spectacular developments in trapping and cooling neutral atoms, which had been more difficult to achieve than trapping ions. Particularly effective laser cooling results from the use of three pairs of oppositely directed laser-cooling beams along three mutually perpendicular paths. A moving atom is then slowed down in whatever direction it moves. This effect gives rise to the designation "optical molasses." Neutral-atom traps can store higher densities of atoms than can ion traps, because ions, being electrically charged, are kept apart by their mutual repulsion. Other things being equal, a larger number of atoms result in a higher signal-to-noise ratio.

The main hurdle in using neutral atoms as frequency standards is that the resonanc-

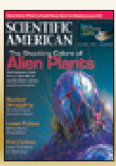
One can envision entire circuits carved out of a graphene sheet. —ANDRE K. GEIM AND PHILIP KIM, 2008

es of atoms in a trap are strongly affected by the laser fields. A device called the atomic fountain surmounts the difficulty. The traps capture and cool a sample of atoms that are then given a lift upward so that they move into a region free of laser light. The atoms then fall back down under the influence of gravity. On the way up and again on the way down, the atoms pass through an oscillatory field. In this way, resonance transitions are induced, just as they are in the separated oscillatory field beam apparatus.

Much current research is directed toward laser-cooled ions in traps that resonate in the optical realm, where frequencies are many thousands of gigahertz. Such standards provide a promising basis for accurate clocks because of their high Q. Investigators at NIST have observed a Q of 10^{13} in the ultraviolet resonance of a single laser-cooled, trapped ion. This value is the highest Q that has ever been seen in an optical or microwave atomic resonance.

The anticipated improvements in standards will increase the effectiveness of the current uses and open the way for new functions. Only time will tell what these uses will be.

Carbon Wonderland



By Andre K. Geim and Philip Kim

PUBLISHED IN APRIL 2008

NOBEL PRIZE IN 2010 (GEIM)

Every time someone scribes a line with a pencil, the resulting mark includes bits of the hottest new material in physics and nanotechnology: graphene. Graphite, the "lead" in a pencil, is a kind of pure carbon formed from flat, stacked layers of atoms. Graphene is the name given to one such sheet. It is made up entirely of carbon atoms bound together in a network of repeating hexagons within a single plane just one atom thick. Not only is it the thinnest of all possible materials, it is also extremely strong and stiff. Moreover, in its pure form it conducts electrons faster at room temperature than any other substance. Engineers at laboratories worldwide are currently scrutinizing the stuff to determine whether it can be fabricated into smart displays, ultrafast transistors and quantum-dot computers.

In the meantime, the peculiar nature of graphene at the atomic scale is enabling physicists to delve into phenomena that must be described by relativistic quantum physics. Investigating such phenomena has heretofore been the exclusive preserve of astrophysicists and high-energy particle physicists working with multimillion-dollar telescopes or multibillion-dollar particle accelerators. Graphene makes it possible for experimenters to test the predictions of relativistic quantum mechanics with laboratory benchtop apparatus.

Two features of graphene make it an exceptional material. First, despite the relatively crude ways it is still being made, graphene exhibits remarkably high quality—resulting from a combination of the purity of its carbon content and the orderliness of the lattice into which its carbon atoms are arranged. Investigators have so far failed to find a single atomic defect in graphene—say, a vacancy at some atomic position in the lattice or an atom out of place. That perfect crystalline order seems to stem from the strong yet highly flexible interatomic bonds, which create a substance harder than diamond yet allow the planes to bend when mechanical force is applied. The quality of its crystal lattice is also responsible for the remarkably high electrical conductivity of graphene. Its electrons can travel without being scattered off course by lattice imperfections and foreign atoms.

The second exceptional feature of graphene is that its conduction electrons move much faster and as if they had far less mass than do the electrons that wander about through ordinary metals and semiconductors. Indeed, the electrons in graphene—perhaps "electric charge carriers" is a more appropriate term—are curious creatures that live in the weird world where rules analogous to those of relativistic quantum mechanics play an important role. That kind of interaction inside a solid, so far as anyone knows, is unique to graphene. Thanks to this novel material from a pencil, relativistic quantum mechanics is no longer confined to cosmology or high-energy physics; it has now entered the laboratory.

One engineering direction deserves special mention: graphene-based electronics. We have emphasized that the charge carriers in graphene move at high speed and lose relatively little energy to colliding with atoms in its crystal lattice. That property should make it possible to build ballistic transistors, ultrahigh-frequency devices that would respond much more quickly than existing transistors.

Even more tantalizing is the possibility that graphene could help the microelectronics industry prolong the life of Moore's law. The remarkable stability and electrical conductivity of graphene even at nanometer scales could enable the manufacture of individual transistors substantially less than 10 nanometers across and perhaps even as small as a single benzene ring. In the long run, one can envision entire integrated circuits carved out of a single graphene sheet.

Whatever the future brings, the one-atom-thick wonderland will almost certainly remain in the limelight for decades to come. Engineers will continue to work to bring its innovative by-products to market, and physicists will continue to test its exotic quantum properties. But what is truly astonishing is the realization that all this richness and complexity had for centuries lain hidden in nearly every ordinary pencil mark.

John Matson *and* **Ferris Jabr** *are associate editors at* **Scientific American.**

MORE TO EXPLORE

Black Holes and Time Warps: Einstein's Outrageous Legacy. Kip S. Thorne. W. W. Norton, 1995.

The Strangest Man: The Hidden Life of Paul Dirac, Mystic of the Atom. Graham Farmelo. Basic Books, 2009.

From Eternity to Here: The Quest for the Ultimate Theory of Time. Sean Carroll. Plume, 2010.

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Do animals other than humans have a sense of humor? Maybe so

By Jesse Bering

ANIMAL BEHAVIOR

THE RAT THAT LAUGHED

ONCE, WHILE IN A DROWSY, ALTITUDE-INDUCED DELIRIUM 35,000 FEET SOMEWHERE OVER ICELAND, I groped mindlessly for the cozy blue blanket poking out beneath my seat, only to realize—to my unutterable horror—that I was in fact tugging soundly on a wriggling, sock-covered big toe. Now, with a temperament such as mine, life tends to be one awkward conversation after the next, so when I turned around, smiling, to apologize to the owner of this toe, my gaze was met by a very large man whose grunt suggested that he was having some difficulty in finding the humor in this incident.

Adapted from Why Is the Penis Shaped Like That? … And Other Reflections on Being Human, *by Jesse Bering, by arrangement with Scientific American/ Farrar, Straus and Giroux, LLC (North America), Transworld Ltd (UK), Jorge Zahara Editora Ltda (Brazil). Copyright © 2012 by Jesse Bering.*

Unpleasant, sure, but I now call this event serendipitous. As I rested my head back against that sanitation-paper-covered airline pillow, my midflight mind lit away to a much happier memory, one involving another big toe, yet this one belonging to a noticeably more good-humored animal than the one sitting behind me. This other toe—which felt every bit as much as its overstuffed human equivalent did, I should add—was attached to a 450-pound western lowland gorilla, with calcified gums, named King. When I was 20 and he was 27, I spent much of the summer of 1996 with my toothless friend King, listening to Frank Sinatra and the Three Tenors, playing chase from one side of his exhibit to the other, and tickling his toes. He'd lean back in his night house, stick out one huge ashen-gray foot

Illustration by Jonathan Bartlett

through the bars of his cage and leave it dangling there in anticipation, erupting in shoulder-heaving guttural laughter as I'd grab hold of one of his toes and gently give it a palpable squeeze. He almost couldn't control himself when, one day, I leaned down to act as though I were going to bite on that plump digit. If you've never seen a gorilla in a fit of laughter, I'd recommend searching out such a sight before you pass from this world. It's something that would stir up cognitive dissonance in even the heartiest of creationists.

Do animals other than humans have a sense of humor? Perhaps in some ways, yes. But in other ways there are likely uniquely human properties to such emotions. Aside from anecdotes, we know very little about nonhuman primate laughter and humor, but some of the most significant findings to emerge in comparative science over the past decade have involved the unexpected discovery that rats—particularly juvenile rats—laugh. That's right: rats laugh. At least, that's the unflinching argument being made by researcher Jaak Panksepp, who published a remarkable, and rather heated, position paper on the subject in *Behavioural Brain Research*.

In particular, Panksepp's work has focused on "the possibility that our most commonly used animal subjects, laboratory rodents, may have social-joy type experiences during their playful activities and that an important communicative-affective component of that process, which invigorates social engagement, is a primordial form of laughter." Now, before you go imagining some chortling along the lines of one rakish Stuart Little (or was he a mouse?), real rat laughter doesn't tend to sound very much like the human variety, which normally involves pulsating sound bursts starting with a vocalized inhalation and consisting of a series of short distinct saccades separated by almost equal time intervals. The stereotypical sound of human laughter is an aspirated *h,* followed by a vowel, usually *a,* and largely because of our larynx is rich in harmonics. In contrast, rat laughter comes in the form of high-frequency 50-kilohertz ultrasonic calls, or "chirps," that are distinct from other vocal emissions in rats. Here's how Panksepp describes his discovery of the phenomenon:

> *Having just concluded perhaps the first formal (i.e., well-controlled) ethological analysis of rough-and-tumble play in the human species in the late 1990s, where laughter was an abundant response, I had the "insight" (perhaps delusion) that our 50-kHz chirping response in playing rats might have some ancestral relationship to human laughter. The morning after, I came to the lab and asked my undergraduate assistant at the time to "come tickle some rats with me."*

Over the ensuing years Panksepp and his research assistants systematically conducted study after study on rat laughter, revealing a striking overlap between the functional and expressive characteristics of this chirping response in young rodents and laughter in young human children. To elicit laughter in his rat pups, Panksepp used a technique that he called "heterospecific hand play," which is essentially just jargon for tickling.

Rats are particularly ticklish, it seems, in their nape area, which is also where juveniles target their own play activities such as pinning behavior [when one rat pins another on its back]. Panksepp soon found that the most ticklish rats—which, empirically, means simply those rats that emitted the most frequent, robust and reliable 50-kHz chirps in human hands—were also the most naturally playful individuals among the rat subjects. And he discovered that inducing laughter in young rats promoted bonding: tickled rats would actively seek out specific human hands that had made them laugh previously. In addition, and as would be expected in humans, certain aversive environmental stimuli dramatically reduced the occurrence of laughter among rodent subjects.

For example, even when tickling stimulation was kept constant, chirping diminished significantly when the rat pups got a whiff of cat odor, when they were very hungry or when they were exposed to unpleasant bright lights during tickling. Panksepp also discovered that adult females were more receptive to tickling than males, but in general it was difficult to induce tickling in adult animals "unless they have been tickled abundantly when young." Finally, when rat pups were given the choice between two different adults—one that still spontaneously chirped a lot and one that did not—they spent substantially more time with the apparently happier grown-up rat.

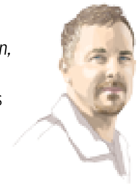
Perhaps not surprisingly, Panksepp has encountered an unfortunate resistance to his interpretation of this body of findings, especially among his scientific colleagues. Yet he protests:

> *We have tried to negate our view over and over, and have failed to do so. Accordingly, we feel justified in cautiously advancing and empirically cultivating the theoretical possibility that there is some kind of an ancestral relationship between the playful chirps of juvenile rats and infantile human laughter.*

Now, Panksepp would be the first to acknowledge that his findings do not imply that rats have a "sense of humor," only that there appear to be evolutionary contiguities between laughter in human children during rough-and-tumble play and the expression of similar vocalizations in young rats. A sense of humor—especially adult humor—requires cognitive mechanisms that may or may not be present in other species. He does suggest, however, that this may be an empirically falsifiable question: "If a cat … had been a persistently troublesome feature of a rat's life, might that rat show a few happy chirps if something bad happened to its nemesis? Would a rat chirp if the cat fell into a trap or was whisked up into the air by its tail? We would not recommend such mean-spirited experiments to be conducted but would encourage anyone who wishes to go in that direction to find more benign ways to evaluate those issues."

Differences between laughing "systems" among mammals are reflected by cross-species structural differences in brain regions as well as in vocal architecture. In the same issue of *Behavioural Brain Research,* neuropsychologist Martin Meyer and his colleagues describe these differences in rich detail. Although brain-imaging studies of human participants watching funny cartoons or listening to jokes reveal the activation of evolutionarily ancient

Jesse Bering is a frequent contributor to *Scientific American,* Slate and *Das Magazin* (Switzerland). Bering is the former director of the Institute of Cognition and Culture at Queen's University, Belfast. He lives near Ithaca, N.Y.



structures such as the amygdala and nucleus accumbens, more recently evolved, "higher-order" structures are also activated, including distributed regions of the frontal cortex. So although nonhuman primates laugh, human humor seems also to involve more specialized cognitive networks that are unshared by other species.

Laughter in our own species, of course, is triggered by a range of social stimuli and occurs under a wide umbrella of emotions, not always positive. To name just a few typical emotional contexts for laughter, it can accompany joy, affection, amusement, cheerfulness, surprise, nervousness, sadness, fear, shame, aggression, triumph, taunt and schadenfreude (pleasure in another's misfortune). But typically laughter serves as an emotionally laden social signal and occurs in the presence of others, which led psychologist Diana Szameitat and her team to explore the possible adaptive function of human laughter. Their study, published in *Emotion,* provides the first experimental evidence demonstrating that human beings possess an uncanny ability to detect a laugher's psychological intent by the phonetic qualities of laugh sounds alone. And sometimes, the authors point out, laughter signals some very aggressive intentions, a fact that should—from an evolutionary perspective—motivate appropriate, or biologically adaptive, behavioral responses on the part of the listener.

Now, it's difficult, if not impossible, to induce genuine, discrete emotions under controlled laboratory conditions, so for their first study Szameitat and her colleagues did the next best thing: they hired eight professional actors (three men and five women) and recorded them laughing. This isn't ideal, obviously, and the researchers acknowledge the limited applicability of using "emotional portrayals" rather than genuine emotions. But "the actors were instructed to focus exclusively on the experience of the emotional state but not at all on the outward expression of the laughter." Here are the four basic laughing types that the actors were asked to perform, along with the sample descriptions and scenarios used to facilitate the actors' getting into character for their roles:

Joyful laughter. *Meeting a good friend after not having seen him for a very long time.*

Taunting laughter. *Laughing at an opponent after having defeated him. It reflects the emotion of sneering contempt and serves to humiliate the listener.*

Schadenfreude laughter. *Laughing at another person to whom a misfortune has happened, such as slipping in dog dirt. As opposed to taunting, however, the laugher does not want to seriously harm the other person.*

Tickling laughter. *Laughing when being physically, literally, tickled.*

Once these recordings were collected, 72 English-speaking participants were invited to the laboratory, given a set of headphones and instructed to identify the emotions behind these laughter sequences. These people listened to a lot of laugh sequences—429 laugh tracks total, each representing a randomly interspersed laugh pulse ranging from three to nine seconds in length, so that there were 102 to 111 laughs per emotion. (This took them about an hour, a nightmarish thought reminding me of those 1980s television sitcoms and focusing my attention on the peculiar laugh tracks in the background.) But the findings were impressive; the participants were able to correctly classify these laugh tracks by their often subtly expressed emotions significantly above chance.

In a second study, the procedure was nearly identical, but participants were asked a different set of questions concerning the social dynamics. Specifically, for each laugh track, they were asked whether the "sender" (that is, the laugher) was in a physically excited or a calm state, whether he or she was dominant or submissive relative to the "receiver" (that is, the subject of the laugh), in a pleasant or unpleasant state, and whether he or she was being friendly or aggressive toward the receiver. For this second study, there was no "correct" or "incorrect" response, because perceiving these characteristics in the laugh tracks involved subjective attributions. Yet, as predicted, each category of laughter (joy, taunting, schadenfreude, tickling) had a unique profile on these four social dimensions. That is to say, the participants used these sounds to reliably infer specific social information regarding the unseen situation. Joy, for example, invoked judgments of low arousal, submissiveness and positive valence on both sides. Taunting laughter clearly stood out: it was very dominant and was the only sound that was perceived by the participants as having a negative valence directed at the receiver.

Human humor seems to recruit cognitive networks unshared by other species.

The participants' perception of schadenfreude laughter was especially interesting. It was heard as being dominant but not quite so dominant as taunting; senders who engaged in such laughter were judged as being in a positive state, more so than taunting but less than tickling. Schadenfreude laughter was heard as being neither aggressive nor friendly toward the receiver but as neutral. According to the authors, whose interpretations of these data again were inspired by evolutionary logic: "Schadenfreude laughter might therefore represent a precise (and socially tolerated) tool to dominate the listener without concurrently segregating him from group context."

I would like to think I was witnessing pure, unadulterated joy in King those many years ago, but of course my brain isn't made to decipher distinct emotive states in gorillas. He has since been laughing, apparently, at Ellen DeGeneres while watching her on television in his cage; two is a small sample size, I realize, but perhaps he finds homosexual human beings particularly comical. In any event, it brings me joy to think of the evolution of joy. And I've got to say, those rat data have me seriously considering a return to my old vegetarianism days—not that I dine on rats, of course, but laughing animals do make the prospect of animal suffering unusually salient and uncomfortable in my mind.

If only dead pigs weren't so spectacularly delicious. SA

SCIENTIFIC AMERICAN ONLINE
For a video that shows rats laughing while being tickled, visit ScientificAmerican.com/jul2012/rat-tickling

Yaser S. Abu-Mostafa is a professor of electrical engineering and computer science at the California Institute of Technology.

ARTIFICIAL INTELLIGENCE

MACHINES THAT THINK FOR THEMSELVES

New techniques for teaching computers how to learn are beating the experts

By Yaser S. Abu-Mostafa

A COUPLE OF YEARS AGO THE DIRECTORS OF A WOMEN'S clothing company asked me to help them develop better fashion recommendations for their clients. No one in their right mind would seek my personal advice in an area I know so little about—I am, after all, a male computer scientist—but they were not asking for my personal advice. They were asking for my machine-learning advice, and I obliged. Based purely on sales figures and client surveys, I was able to recommend to women whom I have never met fashion items I have never seen. My recommendations beat the performance of professional stylists. Mind you, I still know very little about women's fashion.

Machine learning is a branch of computer science that enables computers to learn from experience, and it is everywhere. It makes Web searches more relevant, blood tests more accurate and dating services more likely to find you a potential mate. At its simplest, machine-learning algorithms take an existing data set, comb through it for patterns, then use these patterns to generate predictions about the future. Yet advances in machine learning over the past decade have transformed the field. Indeed, machine-learning techniques are responsible for making computers "smarter" than humans at so many of the tasks we wish to pursue. Witness Watson, the IBM computer system that used machine learning to beat the best *Jeopardy* players in the world.

The most important machine-learning competition did not involve talking *Jeopardy*-playing machines, however. A few years ago Netflix, the online movie rental company, wanted to help its customers find movies that they would love—especially films that were not high-demand "new release" titles but rather from their largely ignored back catalogue. The company already had an in-house movie recommendation system, but executives knew it was far from perfect. So the company launched a competition to improve on existing efforts. The rules were simple: the first entry to beat the performance of the in-house system by 10 percent would earn a $1-million prize. Tens of thousands of people from around the world signed up.

For a machine-learning researcher, the competition was a dream (and not just for the prize money, attractive though it was). The most critical components of any machine-learning system are the data, and the Netflix prize offered 100 million points of real data, ready to download.

TRAINING DAYS

THE NETFLIX COMPETITION lasted for almost three years. Many groups attacked the problem by breaking down individual movies into long arrays of different attributes. For example, you could score any movie on various traits, such as how funny it is, how complicated it is or how attractive the actors are. For each viewer, you go back and take a look at the movies he has reviewed to see how much he values each of these attributes—how much he enjoys comedy, whether he prefers simple or complicated plots, and how much he likes to look at attractive movie stars [*see box on page 81*].

Now prediction becomes a simple matter of matching the

IN BRIEF

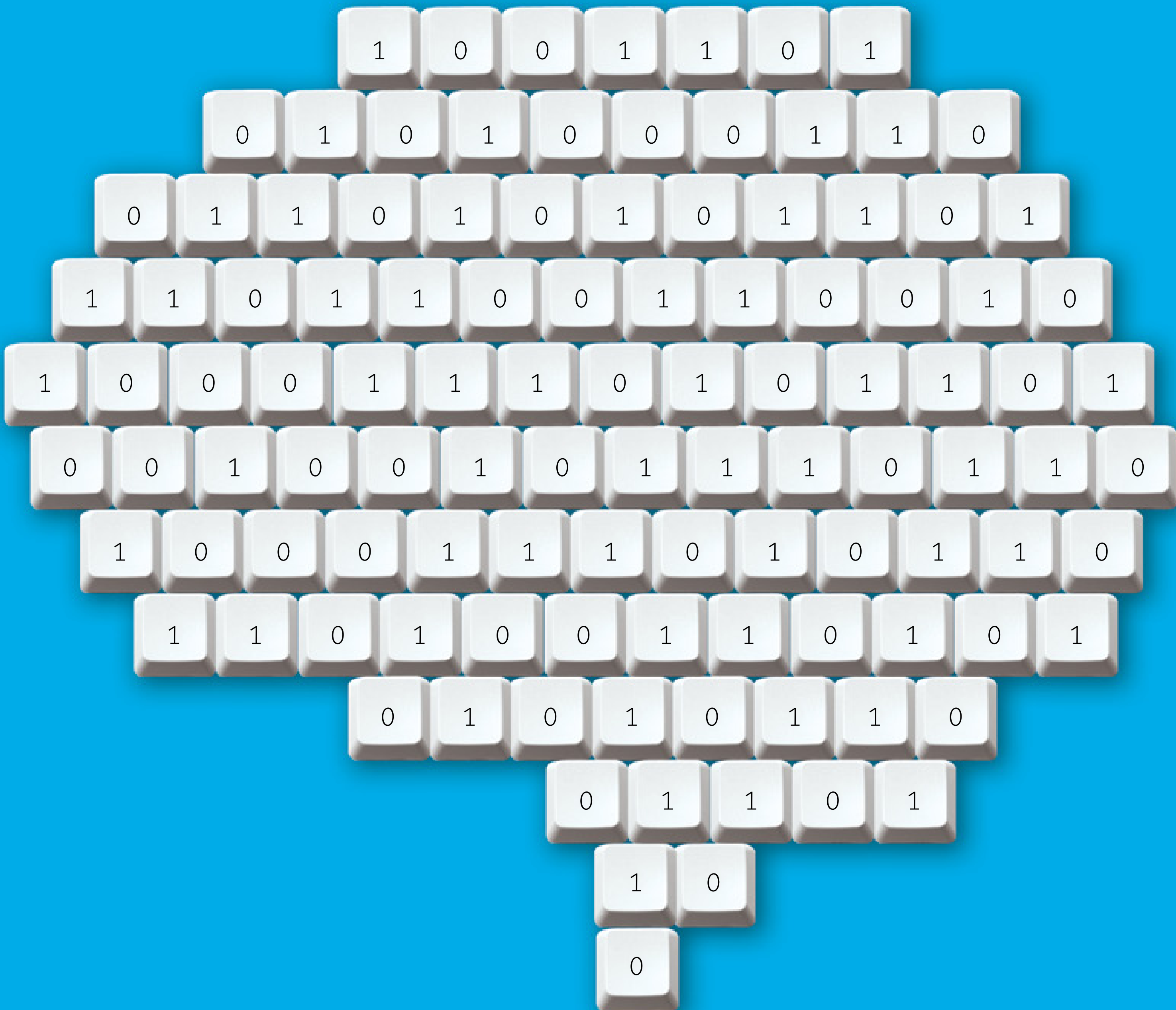
Machine learning is a branch of computer science that combs through data sets to make predictions about the future.

It is used to identify economic trends, personalize recommendations and build computers that appear to think.

Although machine learning has become incredibly popular, it only works on problems with large data sets.

Practitioners of machine learning must be careful to avoid having machines identify patterns that do not really exist.

PHOTOILLUSTRATION BY SCIENTIFIC AMERICAN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viewer's tastes to the new movie's attributes. If he loves comedies and complex plots, chances are he might like a knotty caper such as *Some Like It Hot* or *A Fish Called Wanda*. After the algorithm matches dozens of these attributes, the final recommendation should be a good predictor of how the viewer will like the movie.

We naturally think in easily identifiable attributes such as "comedy" or "complex plot," but algorithms need make no such distinctions. In fact, the entire process is automated—researchers never bother with analyzing movie content. The machine-learning algorithm will start with random, nameless attributes. As it gets data about how viewers rated movies in the past, it fine-tunes attributes until they correspond to how viewers rate movies.

For example, if people who like movie A also tend to like movies B, C and D, the algorithm will come up with a new attribute that is common to A, B, C and D. This happens in the so-called training phase, where the computer searches through millions of viewer ratings. The goal of this phase is to create a set of objective attributes that are based on actual ratings, not on subjective analysis.

It may be hard to interpret the different attributes that the machine-learning algorithm produces; they may not be as straightforward as "comedy content." In fact, they can be quite subtle, even incomprehensible, because the algorithm is only trying to find the best way to predict how a viewer would rate a movie, not necessarily explain to us how it is done. If a system performs well, we do not insist on understanding how it does so.

This is not the way the world is used to operating. Early in my career I developed a credit-approval system for a bank. When I was done, the bank wanted me to interpret what each attribute meant. The request had nothing to do with the system's performance, which was fine. The reason was legal: banks cannot deny credit to someone without articulating a rationale, and they cannot just send a letter to someone saying that the application was denied because X is less than 0.5.

Different machine-learning systems will develop unique sets of attributes. In the final weeks of the Netflix competition, groups that had been working independently began to blend their algorithms using so-called aggregation techniques. In the final hour of the three-year competition, two teams were still fighting for the top prize. The scoreboard showed a slight edge to The Ensemble, a team that included a Ph.D. alumnus of my research group at the California Institute of Technology, over BellKor's Pragmatic Chaos. Yet the final audited tally put the teams in a statistical dead heat—each achieved a 10.06 percent improvement over the original algorithm. According to the rules of the competition, in the event of a tie the award would go to the team that submitted its solution first. After three years of competition and in the last hour of battle, BellKor's Pragmatic Chaos submitted its solution 20 minutes earlier than The Ensemble. A 20-minute delay in a three-year competition made a difference of a million bucks.

THE PERFECT FIT

THE TYPE OF MACHINE LEARNING used in the movie-rating competition is called supervised learning. It is also used in tasks such as medical diagnosis. For example, we could provide a computer with thousands of images of white blood cells from patients' historical records, along with information about whether each image is of a cancerous or noncancerous cell. From this information, the algorithm will learn to apply certain cell attributes—shape, size and color, perhaps—to identify malignant cells. Here the researcher "supervises" the learning process. For each image in the training data, he or she gives the computer the correct answer.

Supervised learning is the most common type of machine learning, but it is not the only one. Roboticists, for example, may not know the best way to make a two-legged robot walk. In that case, they could design an algorithm that experiments with a number of different gaits. If a particular gait makes the robot fall down, the algorithm learns to not do that any more.

This is the reinforcement-learning approach. It is basically trial and error—a learning strategy we are all familiar with. In a typical reinforcement-learning scenario—human or machine—we face a situation in which some action is needed. Instead of someone telling us what to do, we try something and see what happens. Based on what happens, we reinforce the good actions and avoid the bad actions in the future. Eventually both we and the machines learn the correct actions for different situations.

For example, consider Internet search engines. The founders of Google did not wade through the Web circa 1997 to train its computers to recognize pages about, say, "Dolly the sheep." Instead their algorithms crawled the Web to generate a first draft of results, then they relied on user clicks to reinforce which pages were relevant and which were not. When users click on a page link in the search results, the machine-learning algorithm learns that the page is relevant. If users ignore a link that appears at the top of the search results, the algorithm infers that the page is not relevant. The algorithm combines such feedback from millions of users to adjust how it evaluates pages in future searches.

EXCESS PROBLEMS

RESEARCHERS often use reinforcement learning for tasks that require a sequence of actions, such as playing a game. Consider a simple example, like tic-tac-toe. The computer may start by randomly putting an X in a corner. This is a strong move, and the computer will go on to win these games more often than the games that it opens by placing an X on a side. The action that leads to a win—X in the corner—gets reinforced. Researchers then extend this process to infer what the correct action would be at any future step of the game—and for any game, from checkers to Go. Reinforcement learning is also used in advanced economics applications, such as finding a Nash equilibrium.

Sometimes even reinforcement learning is too much to ask for, because we are unable to get feedback on our actions. In such cases, we must turn to "unsupervised learning." Here the researcher has a set of data but no information about what action should be taken—either explicitly, as in supervised learning, or implicitly, as in reinforcement learning. How could we possibly learn from these data? A first step to making sense of it is to categorize the data into groups based on similarity. This is called clustering. It collects unlabeled data and infers information about their hidden structure. Clustering provides us with a better understanding of the data before we consider what action should be taken. Sometimes clustering is enough—if we want to organize a library, simply grouping books into similar categories is all we need to do. At other times, we might go further and apply supervised learning to the clustered data.

Ironically, the biggest trap that machine-learning practitioners fall into is to throw too much computing power at a problem. Recognizing this fact and being able to deal with it properly are what separate the professionals from the amateurs.

How can more power hurt? Machine-learning algorithms try to detect patterns in the data. If the algorithm is too aggressive—perhaps using too sophisticated a model to fit a limited data sample—it may mislead itself by detecting spurious patterns that happen by coincidence in a sample but do not reflect a true association. A significant part of the research on the mathematical theory of machine learning focuses on this problem of "overfitting" the data. We want to detect genuine connections that fit the data, but we do not want to overdo it and end up picking patterns that cannot be trusted.

To understand how this can happen, imagine a gambler at a roulette table (for the sake of simplicity, we will assume this table has only red and black numbers and does not include 0 or 00). She watches 10 consecutive spins alternate between red and black. "The wheel must be biased," she thinks. "It always goes red, black, red, black, red, black." The player has created a model in her head that the limited data set has confirmed. Yet on the 11th roll, right after she puts down $100 on red, the random nature of the wheel reasserts itself. The wheel stops at black for the second consecutive time, and she loses it all.

Our gambler was looking for a pattern where none really exists. Statistically, any roulette table has about a one in 500 chance of randomly flip-flopping between red and black 10 times in a row. In roulette, however, past spins have no bearing on the future. The next spin always has a 50 percent chance of coming up red. In machine learning, we have an old saying: if you torture the data long enough, it will confess.

To avoid this outcome, machine-learning algorithms are biased to keep the models as simple as possible using a technique called regularization. The more complex a model is, the more prone it is to overfitting; regularization keeps that complexity in check.

Researchers will also commonly validate the algorithm on data that are not in the training set. In this way, we ensure that the performance we are getting is genuine, not just an artifact of the training data. The Netflix prize, for instance, was not judged against the original data set provided to the participants. It was tested on a new data set known only to the people at Netflix.

PREDICTING THE FUTURE

IT IS DIFFICULT to get bored if you work in machine learning. You never know what application you could be working on next. Machine learning enables nonexperts in an application area—computer scientists in women's fashion, for example—to learn and predict based merely on data. As a consequence, interest in the field is exploding. This past spring students from 15 different majors took my machine-learning course at Caltech. For the first time, I also posted course materials online and broadcast live videos of the lectures; thousands of people from around the world watched and completed the assignments. (You can, too: see the link below in the More to Explore.)

Machine learning, however, works only for problems that have enough data. Anytime I am presented with a possible machine-learning project, my first question is simple: What data do you have? Machine learning does not create information; it gets the information from the data. Without enough training data that contain proper information, machine learning will not work.

Yet data for myriad fields are becoming ever more abundant, and with them the value of machine learning will continue to rise. Trust me on this—predictions are my specialty. SA

HOW IT WORKS

Rated X (and Y and Z)

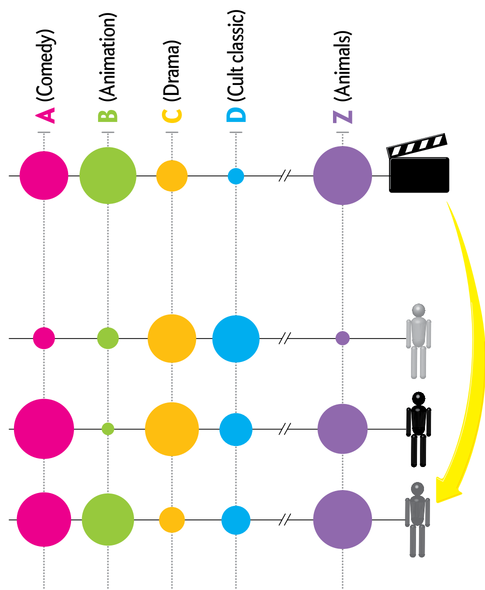
What movie should you watch tonight? Personalized recommendation engines help millions of people narrow the universe of potential films to fit their unique tastes. These services depend on a machine-learning strategy called singular value decomposition, which breaks down movies into long lists of attributes and matches these attributes to a viewer's preferences. The technique can be extended to just about any recommendation system, from Internet search engines to dating sites.

Turn Movies into Data

First a recommendation engine takes a huge data set of films and viewer ratings. Then it uses the collective ratings to break down individual movies into long lists of attributes. The resulting attributes may correspond to easily identifiable qualities such as "comedy" or "cult classic," but they may not—the computer knows them only as X, Y and Z.

Match Viewers to Movies

Now recommendation is a simple matter of decoding an individual's tastes and matching those tastes to the relevant movies. If in the past a person has enjoyed comedies with animals—or with unnamed mystery quality X—the recommendation engine will find similar films.



MORE TO EXPLORE

Machines That Learn from Hints. Yaser S. Abu-Mostafa in *Scientific American,* Vol. 272, No. 4, pages 64–69; April 1995.

Recommend a Movie, Win a Million Bucks. Joseph Sill in *Engineering & Science,* Vol. 73, No. 2, pages 32–39; Spring 2010.

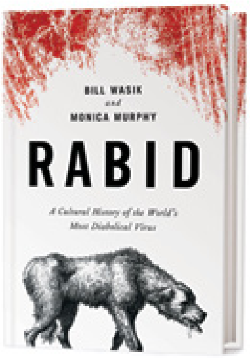
Learning from Data. Yaser S. Abu-Mostafa, Malik Magdon-Ismail and Hsuan-Tien Lin. AMLbook, 2012. **http://amlbook.com**

Learning from Data (online course): **http://work.caltech.edu/telecourse.html**

SCIENTIFIC AMERICAN ONLINE
For an interactive look at how movie-recommendation systems work, visit **ScientificAmerican.com/jul2012/rated-x**

Illustration by Jen Christiansen

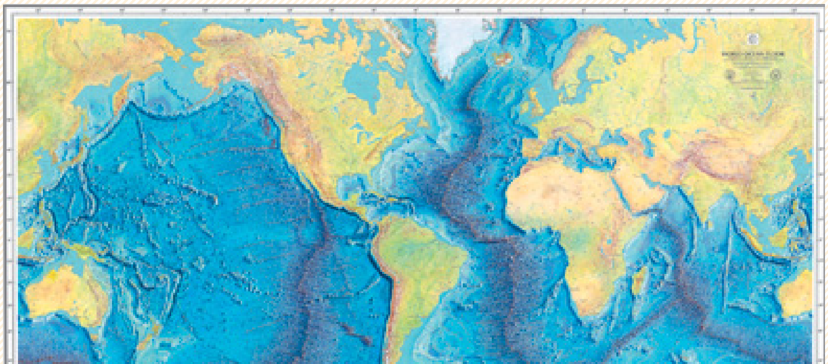
BOOKS



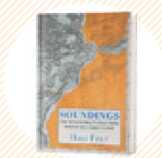
Rabid: A Cultural History of the World's Most Diabolical Virus

by Bill Wasik and Monica Murphy. Viking, 2012 ($25.95)

As Wasik and Murphy warn in their introduction, this book is not for the squeamish. Yet those who are fascinated by how viruses attack the body, by the history of vaccination and by physicians' efforts to save the most desperately ill patients will want to read it. There is also a happy ending: scientists are working to harness rabies as a potent drug delivery vehicle.



OCEAN FLOOR PANORAMA, by Bruce C. Heezen and Marie Tharp, 1977



Soundings: The Story of the Remarkable Woman Who Mapped the Ocean Floor

by Hali Felt. Henry Holt, 2012 ($30)

Felt's own mother was a freelance magazine illustrator who loved drawing maps. That, the author explains, may be what drew Felt to the story of Marie Tharp, a geologist and cartographer who helped to prove the theory of continental drift. Tharp worked at Columbia University with a team that measured the depth of the ocean by recording sonar pings from ships. She turned the data her colleagues brought back from expeditions at sea into the first detailed maps of the mid-oceanic rift system, which bolstered the idea that the earth's surface was made up of tectonic plates.

Homo Mysterious: Evolutionary Puzzles of Human Nature

by David P. Barash. Oxford University Press, 2012 ($27.95)

Barash, a professor of psychology and biology at the University of Washington, has written a highly enjoyable account of things humans have yet to learn about themselves: "known unknowns" he calls them, quoting former secretary of defense Donald Rumsfeld. The evolutionary reasons behind such human characteristics as homosexuality, concealed ovulation, female orgasm, play, and social bonding still perplex scientists, and Barash shares several of the leading theories behind each one. Concealed ovulation, for example, may allow women to exercise greater control over their choice of a sexual partner.

The Irrationals: A Story of the Numbers You Can't Count On

by Julian Havil. Princeton University Press, 2012 ($29.95)

The insides of this book are as clever and compelling as the subtitle on the cover. Havil, a retired former master at Winchester College in England, where he taught math for decades, takes readers on a history of irrational numbers—numbers, like $\sqrt{2}$ or π, whose decimal expansion "is neither finite nor recurring." We start in ancient Greece with Pythagoras, whose thinking most likely helped to set the path toward the discovery of irrational numbers, and continue to the present day, pausing to ponder such questions as, Is the decimal expansion of an irrational number random?

ALSO NOTABLE

FAMILY BOOKS

The Flying Machine Book: Build and Launch 35 Rockets, Gliders, Helicopters, Boomerangs, and More, by Bobby Mercer. Chicago Review Press, 2012 ($14.95)

Scholastic's Discover More series of print books comes with supplemental online material, including **My Body** (ages 4 and up), **Planets** (6 and up) and **The Elements** (9 and up). (from $7.99)

The Ultimate Book of Saturday Science: The Very Best Backyard Science Experiments You Can Do Yourself, by Neil A. Downie. Princeton University Press, 2012 ($29.95)

Ocean Sunlight: How Tiny Plants Feed the Seas, by Molly Bang and Penny Chisholm. Blue Sky Press, 2012 ($17.99)

COMMENT AT ScientificAmerican.com/jul2012

Viewing the world with a rational eye

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

Aunt Millie's Mind

The death of the brain means subjective experiences are neurochemistry

"Where is the experience of red in your brain?" The question was put to me by Deepak Chopra at his Sages and Scientists Symposium in Carlsbad, Calif., on March 3. A posse of presenters argued that the lack of a complete theory by neuroscientists regarding how neural activity translates into conscious experiences (such as "redness") means that a physicalist approach is inadequate or wrong. "The idea that subjective experience is a result of electrochemical activity remains a hypothesis," Chopra elaborated in an e-mail. "It is as much of a speculation as the idea that consciousness is fundamental and that it causes brain activity and creates the properties and objects of the material world."

"Where is Aunt Millie's mind when her brain dies of Alzheimer's?" I countered to Chopra. "Aunt Millie was an impermanent pattern of behavior of the universe and returned to the potential she emerged from," Chopra rejoined. "In the philosophic framework of Eastern traditions, ego identity is an illusion and the goal of enlightenment is to transcend to a more universal nonlocal, nonmaterial identity."

The hypothesis that the brain creates consciousness, however, has vastly more evidence for it than the hypothesis that consciousness creates the brain. Damage to the fusiform gyrus of the temporal lobe, for example, causes face blindness, and stimulation of this same area causes people to see faces spontaneously. Stroke-caused damage to the visual cortex region called V1 leads to loss of conscious visual perception. Changes in conscious experience can be directly measured by functional MRI, electroencephalography and single-neuron recordings. Neuroscientists can predict human choices from brain-scanning activity before the subject is even consciously aware of the decisions made. Using brain scans alone, neuroscientists have even been able to reconstruct, on a computer screen, what someone is seeing.

Thousands of experiments confirm the hypothesis that neurochemical processes produce subjective experiences. The fact that neuroscientists are not in agreement over which physicalist theory best accounts for mind does not mean that the hypothesis that consciousness creates matter holds equal standing. In defense, Chopra sent me a 2008 paper published in *Mind and Matter* by University of California, Irvine, cognitive scientist Donald D. Hoffman: "Conscious Realism and the Mind-Body Problem." Conscious realism "asserts that the objective world, i.e., the world whose existence does not depend on the perceptions of a particular observer, consists entirely of conscious agents." Consciousness is fundamental to the cosmos and gives rise to particles and fields. "It is not a latecomer in the evolutionary history of the universe, arising from complex interactions of unconscious matter and fields," Hoffman writes. "Consciousness is first; matter and fields depend on it for their very existence."

Where is the evidence for consciousness being fundamental to the cosmos? Here Hoffman turns to how human observers "construct the visual shapes, colors, textures and motions of objects." Our senses do not construct an approximation of physical reality in our brain, he argues, but instead operate more like a graphical user interface system that bears little to no resemblance to what actually goes on inside the computer. In Hoffman's view, our senses operate to construct reality, not to reconstruct it. Further, it "does not require the hypothesis of independently existing physical objects."

How does consciousness cause matter to materialize? We are not told. Where (and how) did consciousness exist before there was matter? We are left wondering. As far as I can tell, all the evidence points in the direction of brains causing mind, but no evidence indicates reverse causality. This whole line of reasoning, in fact, seems to be based on something akin to a "God of the gaps" argument, where physicalist gaps are filled with nonphysicalist agents, be they omniscient deities or conscious agents.

No one denies that consciousness is a hard problem. But before we reify consciousness to the level of an independent agency capable of creating its own reality, let's give the hypotheses we do have for how brains create mind more time. Because we know for a fact that measurable consciousness dies when the brain dies, until proved otherwise, the default hypothesis must be that brains cause consciousness. I am, therefore I think. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/jul2012

Illustration by Brian Cairns

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 33 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

Bred and Circuses

A discussion of massive men and tiny tools

When last we met, the subject was athletic performance enhancement. I spoke of modalities for raising one's game, including surgery, lucky genetics and, of course, "eau de Canseco," also known as anabolic steroids. That column contended that many world-class athletes are freaks—of nature, yes, but freaks nonetheless. In effect, they make use of performance-enhancing substances that happen to be produced by their own bodies rather than by a friend of a friend who knows a really good pharmaceutical chemist.

I'll continue to pull on that thread briefly here because within days of that column going to press, news broke that is directly related to the topic. After being lobbied by the union representing its players, the National Football League has agreed to do a study. The investigation will try to determine if football players, who represent the last remnants of a once thriving pre-Clovis North American population of megafauna, naturally have crazy high amounts of compounds that can make one large.

As the *New York Times* put it on April 21, "the union has said that football players, because of their size, might have a higher level of naturally occurring human growth hormone [HGH] and could be at risk of having false positives." At which point, league officials would presumably stand on a chair to raise the level of HGH that counts as a positive test result in pigskin land.

All of which brings me back to the question I asked last time: "If users of performance-enhancing drugs are disqualified, should holders of performance-enhancing mutations be barred, too?" In other words—and I do not know the right answer to this question—why is it okay for a guy to have a body that makes a lot of hormone but not a buddy who makes a lot of hormone to inject?

Speaking of hormones and injections, have you seen "Museum of Copulatory Organs"? Part of the 18th Sydney Biennale in Australia, this collection of 3-D models of insect genitalia was the Ph.D. project of Colombian-born artist Maria Fernanda Cardoso.

Her previous claim to fame was a recreation of a 19th-century-style flea circus, which is paradoxically no small task. A blog post at the Australian Broadcasting Corporation (ABC) Web site quotes Cardoso as saying, "It's one of the hardest things in life to train fleas, it took six years and it requires a lot of patience, no one knew how to train fleas anymore." Actually the New York City subway system still trains fleas on a daily basis, judging by the number of passengers carrying tiny dogs around with them for some reason probably related to the effect of Paris Hilton on our culture.

According to the ABC article, Cardoso was inspired to pursue the copulatory organ project when she found within the flea literature this quote about the insects' penises: "It's not size that matters, it is shape." Indeed, some insect penises come equipped with hooks that enable the ensconced male to grab a previous suitor's sperm packet and remove it from the female. I suggest that these hooks be called cuckholders.

Speaking of shaft-shaped devices used to convey information, have you visited the Cumberland Pencil Museum in England lately? It bills itself as "a great all weather attraction for the whole family," although I would submit that a pencil museum is best appreciated when rain necessitates the cancellation of outdoor festivities. Fortunately for pencil aficionados, this is England.

The museum's Web site speculates that Cumberland locals first struck graphite some five centuries ago, when a violent storm uprooted trees and unearthed vast stores of the carbon allotrope. Shepherds soon used the material to mark their sheep. Meanwhile aspiring scribes wrapped sticks of graphite in sheep hides to make rudimentary pencils. This animal-implement relationship was clearly the source of the old adage "He was as write as a sheep."

Pencils reached their pinnacle in the U.S. in the second half of the 20th century, when millions of high school students clutched No. 2 versions in their clammy hands to mark the answers on their SATs. Some who may not have done well still managed to earn sheepskins by carrying pigskins. SA

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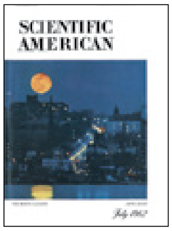
Illustration by Matt Collins

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

Innovation and discovery as chronicled in *Scientific American*



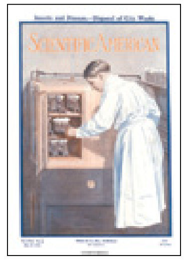
July 1962

Nuclear War Planning

"The May 31 issue of *The New England Journal of Medicine* considers in detail the consequences of the 20 megatons scheduled for Boston in a nuclear attack scenario: 'It is likely that the vectors of epidemic disease would survive radiation injury better than the human population. Eastern equine encephalitis, hepatitis, poliomyelitis and other endemic disease could easily reach epidemic proportions under these circumstances.' Prompt disposal of the dead will be essential for 'control of epidemic disease and its vectors, flies and rodents' and for 'equally important, though less apparent,' psychological reasons. Citing a study by the Office of Civil Defense Mobilization, the authors concur in the view that 'the demolished city must be fenced in or cordoned and placed under quarantine.'"

Shark Danger

"Data from recent experiments may serve to remind bathers, skin divers, small-boat sailors and others who venture into the ocean that there is as yet no sure protection from sharks in open water. It has long been suspected that sharks possess a remarkable ability to locate their prey, often at a considerable distance. Study has accordingly been focused on the sensory organs [*see photograph*] that direct their predatory behavior. —Perry W. Gilbert"



July 1912

Artificial Wave Pool

"Probably no feature of the International Hygiene Exposition held in Dresden last year attracted more general interest than the Undosa artificial surf bath. The receipts from the sale of bath tickets [about six cents apiece] were unexpectedly large, amounting sometimes to $450 in a single day. It is evident that the artificial surf bath may be made a very profitable as well as a very beneficial institution. All persons may derive benefit from the massage effected by the moving water."

For an image of these baths and a slide show on the emergence of leisure time, a moneyed middle class and consumer technology, see www.ScientificAmerican.com/jul2012/leisure

Daring Feats

"Among the well-known vaudeville entertainers must be mentioned Mr. Harry Houdini, whose celebrated feats with handcuffs, strait-jackets and various restraints used to confine the insane and fractious are well known. On Sunday, July 7th, Mr. Houdini invited a party of

SHARK VISION: Zoologist Perry W. Gilbert of Cornell University examines the eye of an anesthetized mako shark (the anesthetic starts to wear off after 20 minutes).

SCIENTIFIC AMERICAN, VOL. 207, NO. 1; JULY 1962 newspaper men and those interested in magic, to witness a very remarkable box-trick on New York Bay. The box, in which Houdini was 'packed for export' was dumped into the water. In exactly a minute and ten seconds Houdini emerged from the water, swimming toward the lifeboat which had been provided. The act was witnessed by thousands of spectators who crowded the decks of three ferryboats."

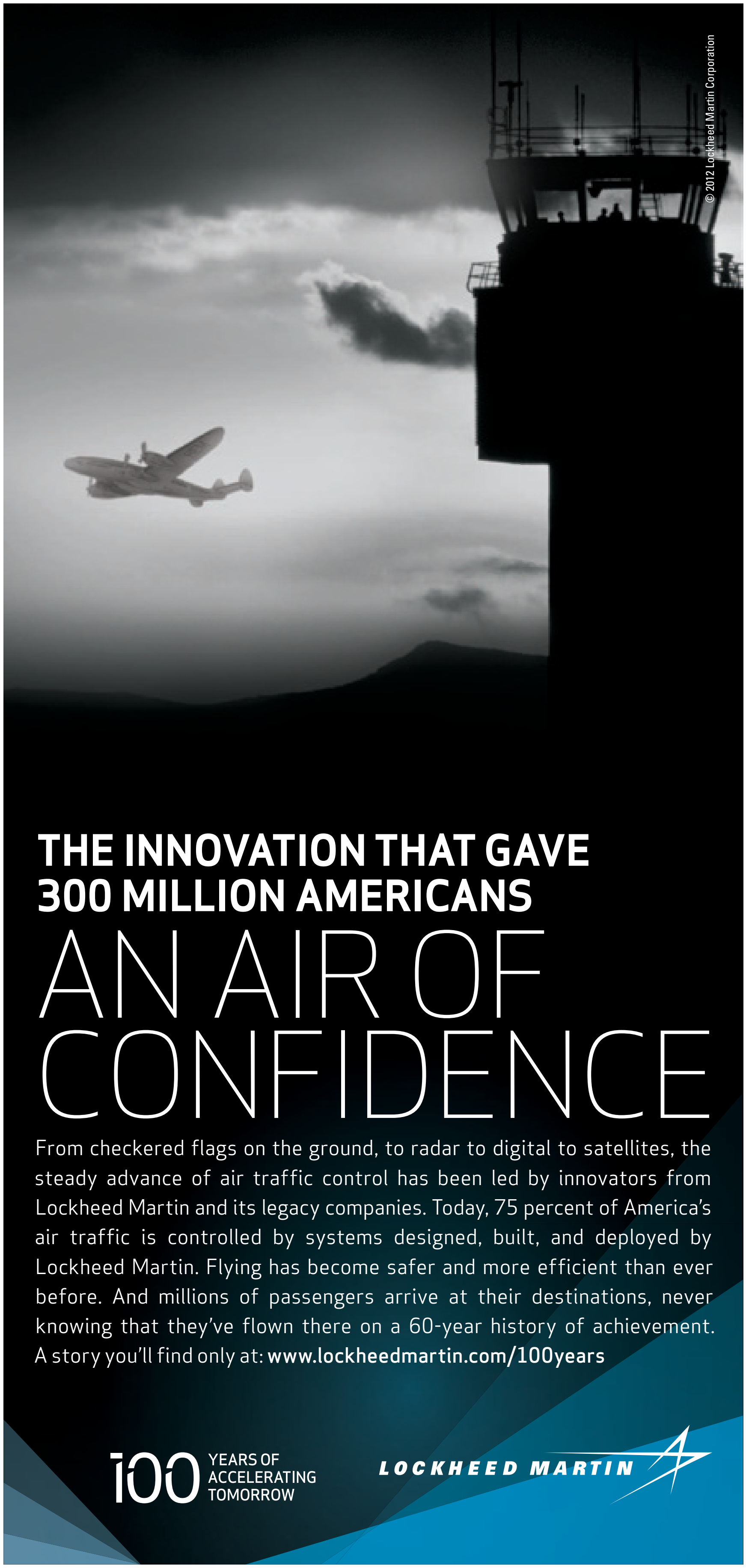
Collisions at Sea

"The wreck of the 'Titanic' was a severe and painful shock to us all; many of us lost friends and acquaintances by this dreadful catastrophe. I asked myself: 'Has Science reached the end of its tether? Is there no possible means of avoiding such a deplorable loss of life and property? Thousands of ships have been lost by running ashore in a fog, hundreds by collisions with other ships or with icebergs, nearly all resulting in great loss of life and property.' At the end of four hours it occurred to me that ships could be provided with what might be appropriately called a sixth sense, which would detect large objects in their immediate vicinity. —Sir Hiram Maxim"
Maxim's concept anticipated SONAR.

July 1862

Rabies Danger

"The most effectual means of preventing dogs biting, and thereby communicating the disease, seems to be muzzling them. M. Renault, the distinguished veterinarian, states that the assertion that muzzling dogs, by the constraint it produces, is itself a cause of rabies, is utterly unsupported by any well-established facts. On the other hand, he points out the results which have been obtained in Berlin. When in 1854 the muzzling was ordered and strictly executed upon all dogs not tied up, the Berlin Veterinary School verified from 1854 to 1861 only nine cases have occurred, and none of these since 1856."



Cognitive Neuroscience, cont.

Windows on the Mind

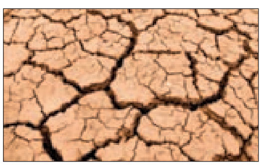
What's the connection behind eye movements and subliminal thought? Join Dr. Macknik and Dr. Martinez-Conde in a look at the latest neurobiology behind microsaccades, the involuntary eye movements that relate to perception and cognition. Learn how microsaccades suggest bias toward certain objects, their relationship to visual illusions, and the pressing questions spurring visual neurophysiologists onward.

Champions of Illusion

The study of visual illusions is critical to understanding the basic mechanisms of sensory perception and advancing cures for visual and neurological diseases. Connoisseurs of illusion, Dr. Macknik and Dr. Martinez-Conde produce the annual Best Illusion of the Year Contest. Study the most exciting novel illusions with them and learn what makes these brain tricks work.

Sleights of Mind

Magic fools us because humans have hardwired processes of attention and awareness that can be "hacked." A good magician employs the mind's own intrinsic properties. Magicians' insights, gained over centuries of informal experimentation, have led to new discoveries in the cognitive sciences, and reveal how our brains work in everyday situations. Get a front-row seat as the key connections between magic and the mind are unveiled!



CLIMATOLOGY

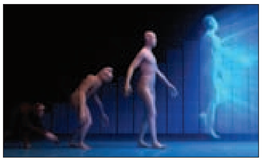
Speaker: Yohay Carmel, Ph.D.

Prioritizing Land for Nature Conservation: Theory and Practice

Forest clearing, climate change, and urban sprawl are transforming our planet at an accelerating rate. Conservation planning prescribes principles and practical solutions for selecting land for protection, assigning land for development, and minimizing the negative impact on nature. Taking a bird's-eye view of approaches to conservation, we'll put the hot topics and tough questions in perspective through an insightful discussion.

Facing a New Mega-Fire Reality

Worldwide, the area, number, and intensity of wildland fires has grown significantly in the past decade. Fire-protection strategies used in the past may not work in the future. Learn the roots and causes of wildfires and recent efforts to predict, manage, and mitigate fire risk. Gain food for thought about the complex interface between science and policy.



HUMAN EVOLUTION

Speaker: Chris Stringer, Ph.D.

Human Evolution: the Big Picture

Time-travel through 6 million years of human evolution, from the divergence from African apes to the emergence of humans. In 1871, Charles Darwin suggested that human evolution had begun in Africa. Learn how Darwin's ideas stand up to the latest discoveries, putting his tenets into context and perspective.

The First Humans

About 2 million years ago the first humans appeared in Africa, distinctly different from their more ancient African ancestors. Discover what drove their evolution and led to a spread from their evolutionary homeland to Asia and Europe. Explore current thinking on the early stages of human evolution.

The Neanderthals: Another Kind of Human

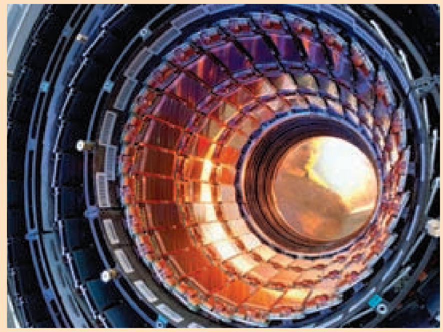
Our close relatives, the Neanderthals, evolved in parallel with *Homo sapiens*. Often depicted as bestial ape-men, in reality they walked upright as well as we do, and their brains were as large as ours. So how much like us were they? What was their fate? Track the evolution of the Neanderthals in light of the latest discoveries.

The Rise of *Homo Sapiens*

Modern humans are characterized by large brains and creativity. How did our species arise and spread across the world? How did we interact with other human species? We will examine theories about modern human origins, including Recent African Origin ("Out of Africa"), Assimilation, and Multiregional Evolution, and delve in to the origins of human behavioral traits.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

INSIDER'S TOUR OF CERN



Pre-cruise: October 22, 2012—From the tiniest constituents of matter to the immensity of the cosmos, discover the wonders of science and technology at CERN. Join Bright Horizons for a private full-day tour of this iconic nuclear-research facility.

Whether you lean toward concept or application, there's much to pique your curiosity. Discover the excitement of fundamental research and get an insider's look at the world's largest particle physics laboratory.

Our full-day tour will be led by a CERN physicist. We'll have an orientation, visit an accelerator and experiment, get a sense of the mechanics of the Large Hadron Collider (LHC), make a refueling stop for lunch, and have time to peruse exhibits and media on the history of CERN and the nature of its work.

This tour includes: Bus transfer from Geneva, Switzerland to our Genoa, Italy hotel (October 23) • 3 nights' hotel (October 20, 21, 22) • 3 full breakfasts (October 21, 22, 23) • Transfers to and from the hotel on tour day (October 22) • Lunch at CERN • Cocktail party following our CERN visit • Do-as-you-please day in Geneva, including transfers to and from downtown (October 21) • Transfer from airport to our Geneva hotel

The price is $899 per person (based on double occupancy). This trip is limited to 50 people. NOTE: CERN charges no entrance fee to visitors.

EPHESUS

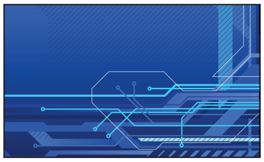
November 1, 2012—Many civilizations have left their mark at Ephesus. It's a complex and many-splendored history, often oversimplified. Bright Horizons pulls together three important aspects of understanding Ephesus that are rarely presented together. You'll meander the Marble Road, visit the legendary latrines, check out the Library, and visit the political and commercial centers of the city. A visit to the Terrace Houses will enhance your picture of Roman-era Ephesus.

We'll take a break for Mediterranean cuisine in the Selcuk countryside, then visit the Ephesus Museum in Selcuk, where city excavation finds are showcased, and you'll get a fuller look at local history, from the Lydians to the Byzantines.

ATHENS

November 1, 2012—The Parthenon and its Acropolis setting are stunning, no doubt about it. Requiring no interpretation, they are ideal for a DIY Athens excursion. On the other hand, visiting the new Acropolis Museum and the National Archaeological Museum with a skilled guide who's on your wavelength adds immeasurably to the experience. We suggest you join Bright Horizons on a focused trip. You'll see the Parthenon frieze, exquisite sanctuary relics, and Archaic sculpture at the Acropolis Museum (as you can see from the picture, the museum sits just below the Acropolis).

Lunch is tucked away at a taverna favored by Athenian families. For dessert, we'll visit the richest array of Greek antiquities anywhere—at the National Archaeological Museum.



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

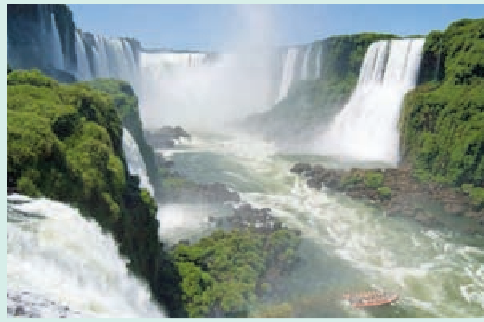
Tackle two challenging questions of our age with Michael Shermer: (1) The origins of morality and (2) the foundations of ethics. Dr. Shermer peels back the inner layers covering our core being to reveal complex human motives — good and evil. Gain an understanding of the evolutionary and cultural underpinnings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

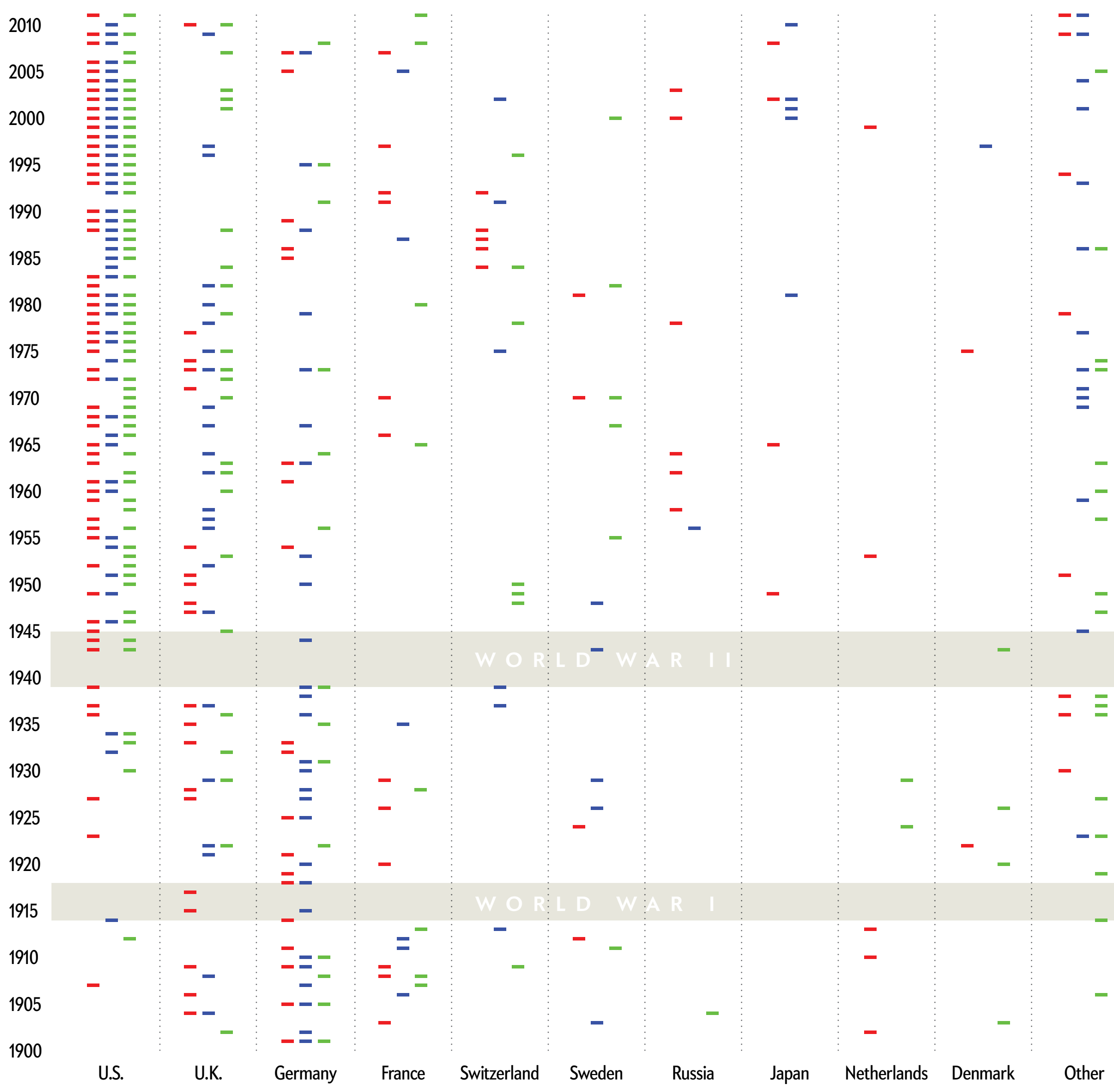
Medal Migrations

The global distribution of Nobel Prizes traces a shift from Europe to the U.S.

Science Nobel Prizes

(color-coded by category and grouped by national affiliation* at time of award)

*Each colored bar represents one or more laureates affiliated with institutions in a given country.



27

Science Nobels won by researchers affiliated with Harvard University or Harvard Medical School—more than any other institution.

4

Members of the extended Curie family who have won Nobels—Marie and Pierre Curie for physics in 1903; Marie Curie for chemistry in 1911; and Irène Joliot-Curie (daughter of Marie and Pierre Curie) and her husband, Frédéric Joliot, for chemistry in 1935.

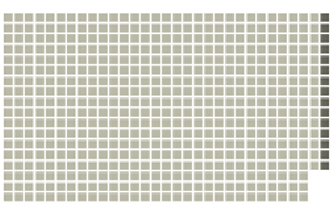
25

Age of the youngest laureate, Lawrence Bragg, who shared the 1915 Nobel Prize in Physics with his father, William Bragg. The next youngest winner was 31 years old.

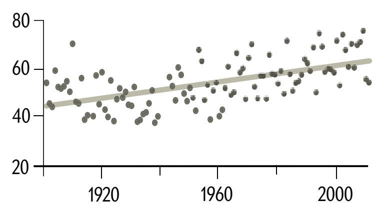
103

Age of the oldest living Nobel laureate, Rita Levi-Montalcini, who shared the Nobel Prize in Physiology or Medicine in 1986.

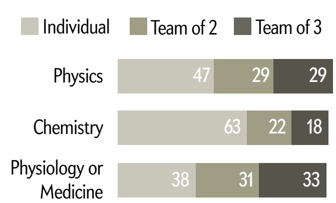
Gender of Winners: 537 men (■), 15 women (■)



Average Age of Winners



Winners per Award



SOURCE: NOBELPRIZE.ORG

SCIENTIFIC AMERICAN ONLINE More on Nobel Prize history at ScientificAmerican.com/jul2012/graphic-science

Graphic by Timeplots