SPACE
To Pluto and Beyond

MEDICINE
Virus Therapy for Cancer

TECHNOLOGY
Objects That Morph on Command

SCIENTIFIC AMERICAN

NOVEMBER 2014

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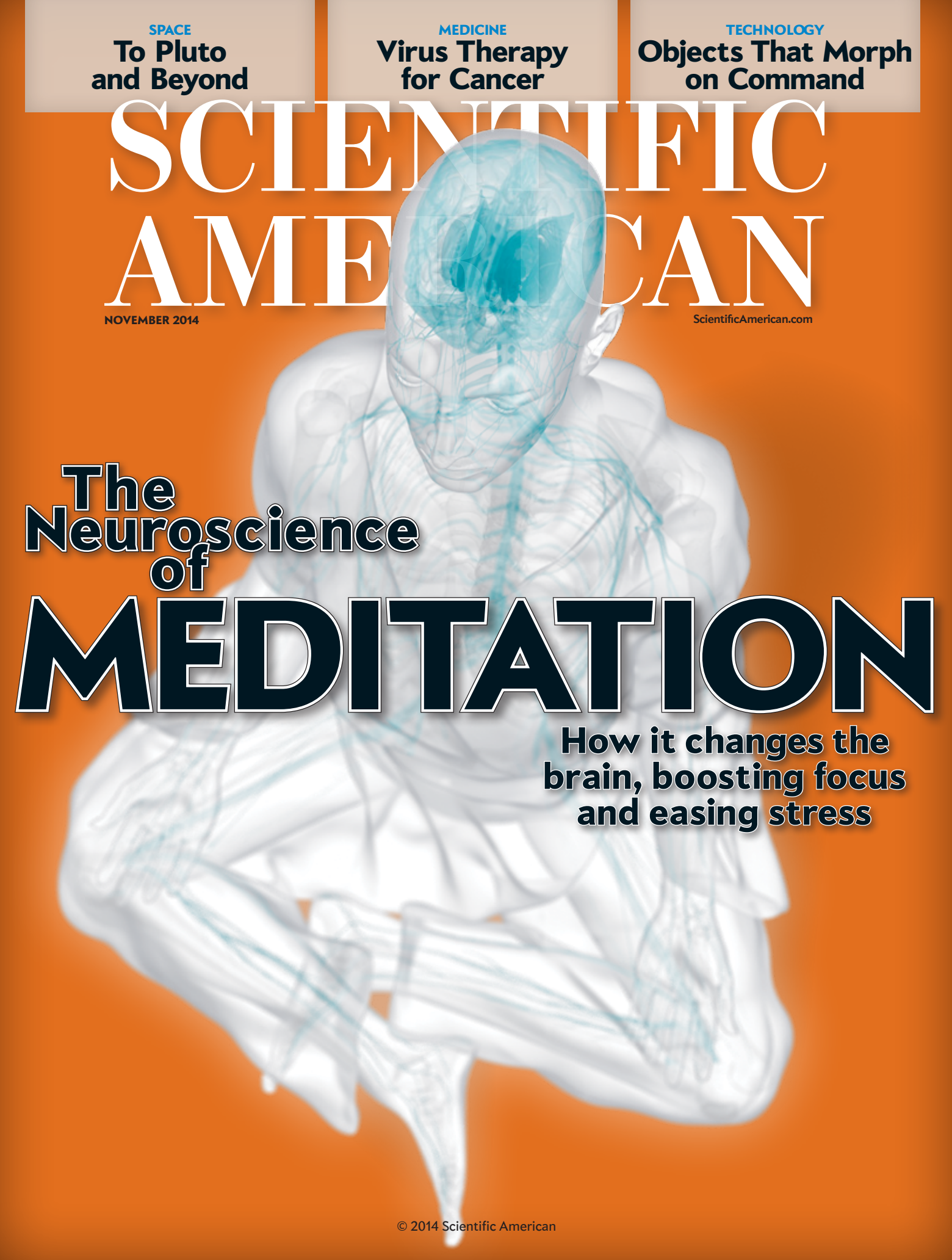

The Neuroscience of MEDITATION

How it changes the brain, boosting focus and easing stress

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It's not about how far you go. It's about how you go far.*
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SCIENTIFIC AMERICAN

November 2014 Volume 311, Number 5

ON THE COVER

Studies on the neurobiology of meditation show that the practice has many of the characteristics of an ideal drug. It counters depression and pain and encourages a sense of well-being. And it does all this with few, if any, side effects, at the cost of a couple of minutes of daily respite from a harried existence. Why don't physicians prescribe it more? Image by Bryan Christie.

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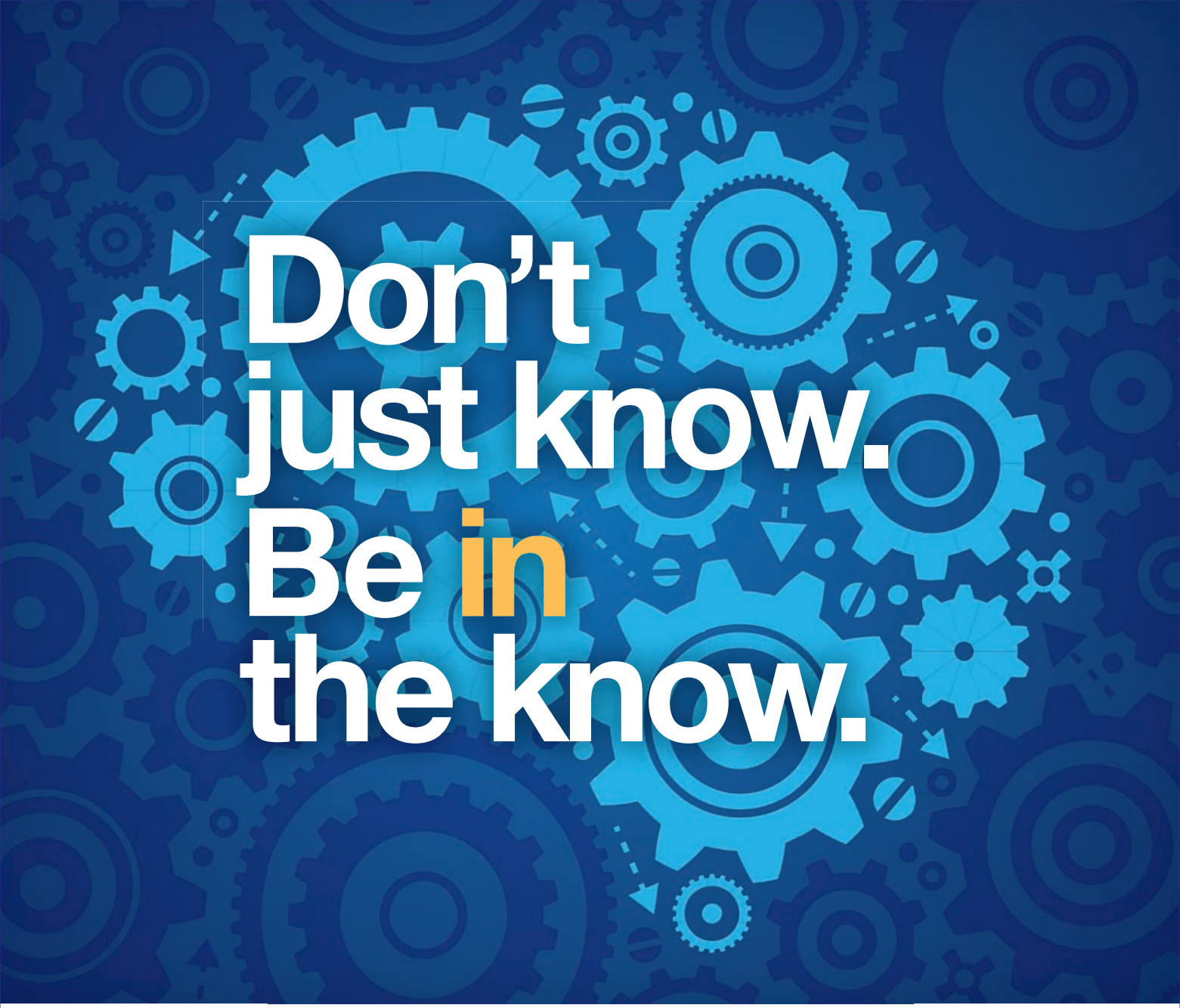
FEATURES

Photograph by Travis Rathbone



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DEPARTMENTS

ON THE WEB

Ongoing Ebola Coverage
Scientific American continues to report on the outbreak in West Africa, as well as Ebola's potential impact globally. *Go to www.ScientificAmerican.com/nov2014/ebola*

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Herbicide and Insecticide Use on GMO Crops Skyrocketing While Pro-GMO Media Run Interference

Former EPA Senior Scientist's New Article Sets Record Straight

By David Bronner, President of Dr. Bronner's Magic Soaps

Michael Specter's recent articles bashing Vandana Shiva and the labeling of genetically engineered foods ("Seeds of Doubt" and "The Problem with G.M.O. Labels," 8/25/14) in The New Yorker are the latest high-profile, pro-GMO articles that fail to engage with the fundamental critique of genetically engineered food crops in U.S. soil today: rather than reduce pesticide inputs, GMOs are causing them to skyrocket in volume and toxicity.

Setting the record straight, Dr. Ramon J. Seidler, Ph.D., former Senior Scientist at the Environmental Protection Agency, has recently published a well-researched article documenting the devastating facts, "Pesticide Use on Genetically Engineered Crops," in the Environmental Working Group's online AgMag. Dr. Seidler's article cites and links to recent scientific literature and media reports and should be required reading for all journalists covering GMOs, as well as for citizens generally to understand why their right to know if food is genetically engineered is so important. The short discussion below summarizes the major points of his article.

Over 99% of GMO acreage is engineered by chemical companies to tolerate heavy herbicide (glyphosate) use and/or to produce insecticide (Bt) in every cell of every plant over the entire growing season. The result is massive selection pressure that has rapidly created pest resistance—the opposite of integrated pest management where judicious use of chemical controls is applied only as necessary. Predictably, just like the overuse of antibiotics in confined factory farms has created resistant "supergerms" leading to animals being overdosed with ever more powerful antibiotics, we now have huge swaths of the country infested with "superweeds" and "superbugs" resistant to glyphosate and Bt, meaning more volume of greater quantities of toxic pesticides are being applied.

For example, the use of systemic insecticides, which coat GMO corn and soy seeds and are incorporated and expressed inside the entire plant, has skyrocketed in the last ten years. This includes the use of neonicotinoids (neonics) which are extremely powerful neurotoxins that contaminate our food and water and destroy non-target pollinators and wildlife such as bees, butterflies and birds. In fact, two neonics in widespread use in the U.S. are currently banned in the EU because of their suspected link to Colony Collapse Disorder in bees.

Mainstream pro-GMO media also fail to discuss the ever-increasing amount of older, much more toxic herbicides like 2,4-D and Dicamba being sprayed, along with huge volumes of glyphosate, to deal with superweeds. Most importantly and egregiously, this biased reporting does not mention the imminent approval of the pesticide industry's next-generation herbicide-tolerant crops that are resistant not only to glyphosate but also to high doses of 2,4-D and Dicamba, which will lead to huge increases of these toxic chemicals being sprayed on our food and farming communities.

The USDA and EPA are in the process of rubber-stamping these into our farming communities (and unlabeled onto our dinner plates) this fall, yet pro-GMO media consistently fail to discuss their imminent approval, even as the lower-toxicity profile of glyphosate is touted. Such reporting gives a free pass to the chemical pesticide industry that pours millions into lobbying government and media elites and defeating voter ballot initiatives to require labeling of GMO foods.

Hopefully Dr. Seidler's article will be widely read and disseminated, so reporters can learn the facts and check their biases against industry-fed distortions. Citizens and consumers need to hear the fundamental concern that GMOs are doubling down on, not freeing us from, the pesticide treadmill that contaminates our food and water while lining the pockets of the chemical companies that make both the GMOs and the pesticides used on them.

David Bronner is President of Dr. Bronner's Magic Soaps, the top-selling brand of natural soaps in North America. He graduated with a degree (B.A.) in Biology from Harvard University in 1995. A leader in the fight to label GMO foods in the U.S., Dr. Bronner's dedicates resources to progressive issues on behalf of the company's mission to use profits to help make a better world.

Read the Seidler article online here: http://bit.ly/1tPDHhl or scan the QR code

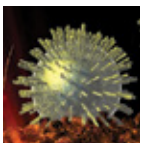
This article was originally published by the Huffington Post on September 15, 2014.

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

Mindful, Medicinal, Malleable and Marketable

Science is, as many observe, a truly collaborative enterprise. It is also one in which practitioners are unafraid to examine evidence and, if the facts point the way, revise previous notions, even if they have been widely held.

This issue's cover story, "Mind of the Meditator," starting on page 38, is such a case. The authors, Matthieu Ricard, Antoine Lutz and Richard J. Davidson, are, respectively, a Buddhist monk (originally trained as a cellular biologist) and two neuroscientists. The topic is the centuries-old practice of meditation, which has some role in nearly every religion and has been gaining attention in the secular world as a means of promoting well-being and calmness. As it turns out, meditation produces actual changes in the brain, as shown by brain scans and various techniques. People who meditate not only have a greater amount of brain tissue in some regions, but they also can withstand stress better and react faster to certain types of stimuli. Something (dare I say it?) to ponder.



"Virus Therapy for Cancer," by Douglas J. Mahoney, David F. Stojdl and Gordon Laird, beginning on page 54, looks at a modern resurgence of an idea dating back to the early 20th century: the use of viruses to treat human cancers. These "oncolytic" viruses replicate extensively inside a tumor, creating an army of virus clones that attack more of the cancerous cells, alone or in combination with other treatments. They can also provoke the body's own immune system to help fight tumors.

While we are contemplating how we rearrange our inner worlds, scientists are also looking into shaping the objects around us. Starting on page 60, "The Programmable World," by Thomas A. Campbell, Skylar Tibbits and Banning Garrett, explains how novel materials and 3-D printers could lead to items, such as houses or robots, that can self-assemble and change shape or function on command.

How much will rooftop solar reshape our notions about home energy? Noting the rise of solar panels, associate editor David Biello takes a sweeping look in his feature article, "Solar Wars," at the issues that have arisen, from utilities' concerns about lost revenue to the need to make sure the right policy frameworks are in place to ensure a reliable electric grid as many homeowners migrate off it. As you will find if you turn to page 66, although there is a long way to go, if done right rooftop solar could help Americans become energy-independent. SA

Illustration by Nick Higgins

Don't Run Out of Money During Retirement

What Investors Should Worry About

It's no secret that the vast majority of Americans entering their retirement years are doing so with vastly underfunded retirement savings. However, even if you have significant financial assets in your retirement savings, assets in excess of $500,000, your hope for a comfortable retirement is hardly assured. In fact, you could be headed for a financial disaster just when you can least afford it.

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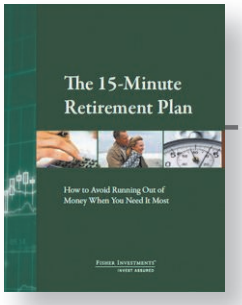

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July 2014

INCOME INEQUALITY

In arguing that wealth inequality has not grown in the U.S. as much as is perceived in "The Myth of Income Inequality" [Skeptic], Michael Shermer ignores that poverty among Americans, particularly youths, is far worse than in other advanced nations. It ruins the lives and educational chances of at least a fifth of young Americans, which makes a mockery of his claim that the U.S. is still the land of equal opportunity.

Bruce J. Biddle
University of Missouri

Shermer's statistics fail to support his argument. He first states that income (not wealth) has not changed much by comparing the relatively affluent 1979 with 2010, the aftermath of the Great Recession. The data he cites include government transfers such as welfare payments and unemployment as "income." Such transfer payments go up dramatically in a recession.

He then asserts that the "pie" of national wealth got bigger between 2012 and 2013. Overall wealth went up then primarily because the stock market was making 30 percent gains after the Great Recession, and corporations were making record unreinvested profits. Who do you suppose benefited from that growth?

Shermer goes on to argue that movement into different income groups was higher within the top 1 percent and top

"You need to look elsewhere than IRS records to discover how much the rich get richer."

RICHARD USCHOLD *VIA EMAIL*

0.01 percent slices of income taxpayers between 1996 and 2005 than among the 20 percent slices of lower taxed groups. Ignoring dramatic changes in tax policy in those years, there is simply no way to expect that anything, taxpayers included, will remain within a narrow range as often as within a range 20 or 2,000 times larger.

Hugh Walkup
Alexandria, Va.

Comparing the income of rich and poor people is misleading. The majority of the rich don't collect much as salaries or wages; they have other methods of wealth accumulation, such as capital gains, which are reported only when an asset is sold. You need to look elsewhere than IRS records to discover how much the rich get richer.

The Rich and the Rest of Us, by Tavis Smiley and Cornel West, asserts that from 1983 to 2009, the top 20 percent took *more than* 100 percent of the wealth gain, and the bottom 60 percent *lost* net worth.

Richard Uschold
via e-mail

SHERMER REPLIES: As noted in the numerous responses to my column, there are many ways to compute income inequality. I did not intend to deny that the rich have gotten richer more than the poor have gotten richer, only that the differences between rich and poor are not as great as most people think. In my new book, The Moral Arc, *I go into much more detail on the nuances of the discussion, but here let me make the general point that the trend lines are moving in the right direction.*

According to a 2002 analysis, in the year 1820, 94 percent of the world's population was in poverty, and 84 percent was in extreme poverty (defined as living on less than $2 and $1 a day, respectively, in 1985 purchasing power parity, or PPP). The World Bank reports that by 1981, the figure of those living under its threshold for poverty ($1.25 per day in 2005 PPP) had dropped to 52 percent, and by 2010 it had fallen to 21 percent. That's still far too many impoverished people, but several economists predict that the figure will be 0 percent by 2100 and possibly even by 2050. If that isn't progress, I don't know what is.

The Bill & Melinda Gates Foundation optimistically projects poverty's end by 2035 (http://annualletter.gatesfoundation.org/#section=myth-one), but of course the date very much depends on how actively we work toward that goal.

POTTY TO POTABILITY

In "Bottoms Up," Olive Heffernan's article about converting sewage to tap water, one important factor was omitted: reliability. No set of equipment runs perfectly forever; unexpected problems always arise and often escalate to levels that could easily cause dangerous health problems.

With tap water as the product, extreme measures of automation and quality monitoring must be applied to handle all possible faults in the system and to shut it down at the first indication of a problem.

R. W. Lowrie
Dade City, Fla.

Heffernan's description of a process by which sewage is treated to become potable tap water includes a step to remove salts called reverse osmosis. What's not obvious is why this is easier than treating seawater, which is even more plentiful.

Greg Arzoomanian
Providence, R.I.

The article says purified wastewater contains substances such as hand cleanser "in such minute doses as to be harmless." But if the water is continually recycled and these compounds are not broken down, might they become more concentrated over time? Also, can we really assume that they are harmless in minute doses?

Tom Fitz
Northland College

HEFFERNAN REPLIES: Lowrie is right that no system runs reliably forever, and monitoring at each stage of the process

would be crucial for any potable reuse system. Part of the rationale for having a multiple-barrier or multiple-step system in San Diego is so that each step can be monitored, and the plant could be temporarily closed should any of those crucial barriers fail. The aim would be to provide a fail-proof system for delivering clean drinking water to the city.

In response to Arzoomanian: Converting sewage into potable tap water is not necessarily easier than treating seawater. There are a number of steps involved in creating potable water from sewage in addition to reverse osmosis. But purifying sewage is likely to be cheaper and is better for the environment, making it a potentially more attractive option than desalination. For a start, the product being treated is already available on site at a wastewater treatment plant, avoiding the energy and infrastructure required for pumping water from the sea. What is more, there is a large amount of waste brine involved in desalination, which needs to be disposed of. In comparison, sewage needs to be treated anyhow and, in the case of San Diego, would end up being disposed of at sea—and polluting coastal waters—if it was not converted to drinking water.

Regarding Fitz's question: Although it is not possible to completely eliminate exposure to small doses of contaminants such as pharmaceuticals and personal care products when treating sewage, the system used at the San Diego Advanced Water Purification Facility aims to reduce this risk to a very low level and to prevent the accumulation of those substances with numerous treatment steps. This has the added advantage of protecting the water supply should one of the approaches fail.

ERRATA

Because of an editing error, "Giant Bubbles of the Milky Way," by Douglas Finkbeiner, Meng Su and Dmitry Malyshev, referred to M42 as a nearby galaxy with Fermi bubbles. M42 is a nebula. The authors meant to speak of the M82 galaxy.

"How to Curb an Epidemic," by Annie Sneed [Advances], describes the application of the anti-HIV microbicide tenofovir gel, now in testing, as occurring before sex. It is instead applied both before and after sex.

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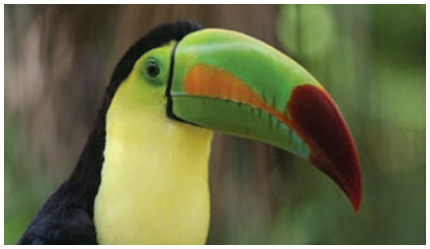

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Lightning

Speaker: Joseph R. Dwyer, Ph.D.

The Mysteries of Lightning

While lightning is one of the most widely recognized natural phenomena, it remains poorly understood. Learn what we do and don't know about lightning, including the recent discovery that lightning emits bursts of x-rays and gamma-rays. By measuring these high-energy emissions, researchers are gaining a better understanding of this fascinating phenomenon.

Ball Lightning

Ball lightning has been reported by eyewitnesses as a grapefruit-sized glowing sphere as bright as a 60-watt light bulb, often seen along with thunderstorms. Yet little is known about ball lightning, and it has never been replicated in the lab. We'll discuss amazing reports of ball lightning and some of the latest explanations.

Sprites, Pixies, and Other Atmospheric Phenomena

Although we spend our entire lives inside our atmosphere, there are surprisingly many things that we don't know about the air right over our heads. Learn about strange discharge phenomena dubbed sprites, elves, trolls, pixies, and gnomes, and other amazing atmospheric curiosities.

Lightning Safety

Lightning strikes our planet about 4 million times every day, causing billions of dollars in property damage and killing or injuring many people each year. Despite the dangers, many people don't know how to be safe during thunderstorms. Learn about the harmful effects of lightning, along with lightning protection and safety.

The Maya

Speaker: Joel Palka, Ph.D.

Archaeological Highlights of Maya Civilization

From over a century of excavations in Mexico and Central America, we understand when Maya society formed, how their cities flourished in the tropical forests, and how they lived their daily lives, yet some mysteries of the Maya remain. We'll overview this fascinating civilization and some of the questions we still have.

Maya Hieroglyphic Writing for Everyone

Maya hieroglyphs present exciting details on ancient Maya life including religion, politics, trade, and the organization of society. We'll cover the deciphering of Maya writing, the structure of the texts, and basic knowledge of Maya culture through their hieroglyphs.

Native Maya Perspectives of the Sea

For many of us the sea represents beauty and wonder, but how did indigenous Maya people

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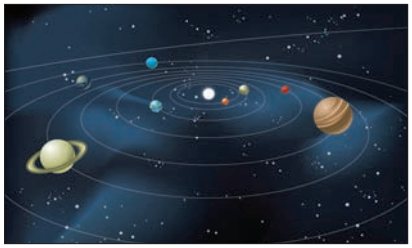
view the sea? We'll focus on Maya culture and the sea as seen in painted pottery, monumental sculpture, and colonial-era narratives.

Maya Pilgrimage to Ritual Landscapes

Recent archaeological and anthropological findings have shed new light on ancient Maya travel, religion, and views of the landscape. Islands, mountains, caves, and lakes made up sacred places to them. This session looks at the latest interpretations of ancient Maya pilgrimage, their ritual landscapes, and how these were central to Maya society.



Our Solar System

Speaker: Adriana C. Ocampo, Ph.D.

Cosmic Collision: The Search for the Dinosaur Killer

Around 65 million years ago a massive space rock hit Central America, setting off a biospheric disaster that wiped out the dinosaurs. Take a voyage back in time, via Belize and neighboring Mexico, to explore the impact site of the ancient asteroid that drastically altered the balance of life on Earth.

Our Neighborhood in the Solar System

In this extraordinary time for planetary science we are beginning to understand planetary formation processes that were wholly unknown to us just a short time ago. Guided by the latest scientific insights, we'll discuss how planets form, why asteroids and comets are important, and whether habitable environments exist beyond Earth.

Exploring our Solar System

NASA's robots have now taken us out to 180 astronomical units (AU), or about 180 times the distance from Earth to the Sun. We'll delve into some of their fascinating discoveries, such as the similarities and differences between the gas giant planets and the key role Jupiter plays for Earth.

Neuroscience

Speaker: Lary C. Walker, Ph.D.

Life and its Discontents

Disease is an inescapable fact of life, but our very existence is shaped by our relationship with potential disease agents. We'll explore the biological origins of disease to understand why the brain is vulnerable to a distinctive constellation of disorders as we age.

Scratching Sheep, Mad Cows, and Laughing Death

Follow the incredible scientific odyssey that began in the 18th century with a mysterious disease of sheep and, in the 20th century, bore two Nobel Prizes. Learn about the prion, an infectious protein and possibly the most controversial molecule in the history of medicine.

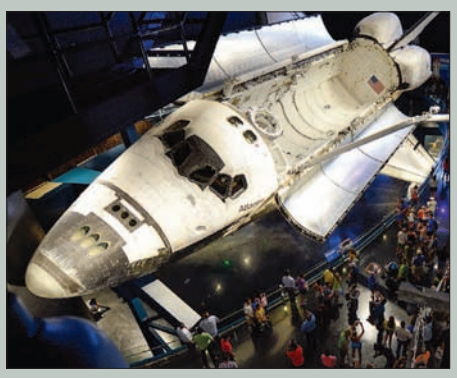
Why Old Brains Falter

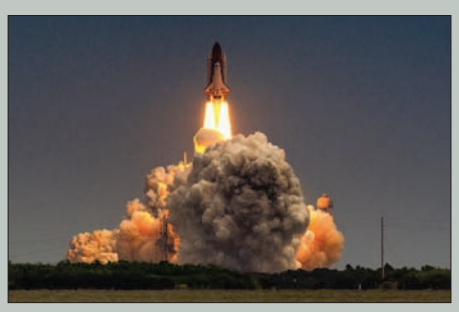
One of the most feared diseases of old age is Alzheimer's disease, the most frequent cause of dementia. Learn how the brain changes in normal aging and in Alzheimer's disease, how Alzheimer's emerges and spreads within the brain, and why it is so difficult to stop.

Alzheimer's Therapies: Hype and Hope

No current treatment can stop the relentless progression of Alzheimer's disease. We'll explore the history of rational therapeutic approaches to Alzheimer's and take a frank look at the benefits and shortcomings of existing treatments. Finally, we'll consider how our growing knowledge of brain aging offers hope that an effective therapy is possible.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS OUTER SPACE AND OPEN SPACE IN FLORIDA





BOK TOWER GARDENS: Sunday, March 22, 11am – 4pm

KENNEDY SPACE CENTER (KSC): Monday, March 23, 8am – 7:30pm

Continue the Bright Horizons fun with a two-day exploration of two very different central Florida gems: Bok Tower Gardens and Kennedy Space Center.

Bok Tower Gardens — a National Historic Landmark botanical garden and bird sanctuary — is an opportunity to relax amidst subtropical landscape gardens which help preserve 64 rare Central and North Florida plant species. We'll also hear the Garden's 60-bell carillon play.

Reconnect with the spirit and substance of space exploration on our visit to Kennedy Space Center. Guided by tour specialists, explore the world's largest launch facility.

First stop: Launch Control Center. Journey inside the firing room where the last 21 shuttle launches were controlled. Pass by the computer consoles at which engineers constantly monitored the launch controls. See the launch countdown clock and large video monitors on the walls. Enter the bubble room with its wall of interior windows through which the management team viewed all of the proceedings below. Re-live the last shuttle launch, Atlantis mission STS-135 (see takeoff photo, below), while watching the launch footage in the room where the launch became part of history.

Get the right stuff at lunch as we meet a veteran member of NASA's Astronaut Corps, have a hot buffet lunch, and participate in a 30-minute interactive Q&A during "Lunch with an Astronaut."

Onward to the Space Shuttle Atlantis, along with the interactive exhibits that bring to life the complex story of the shuttle and the thousands of people who created and maintained it.

Join us for a memorable look at KSC's role in the endeavor of exploration.

Price: $899 per person, based on double occupancy; $1,399 for a single. Kennedy Space Center launch facilities are transitioning to commercial missions and are under construction. Therefore the structures and vantage points we experience and the entire sequence of our day are subject to change. Regardless of our tour route, we will have an excellent tour of KSC!

For more info please email Concierge@InsightCruises.com or visit ScientificAmerican.com/travel

Do No Harm—And No Drugs

Enough physicians have substance abuse problems to make random drug testing a needed part of medical practice

We hold our physicians to high standards because they make life-or-death decisions. Yet when it comes to drug addiction, their behavior can be disturbing. Their overall rates of substance abuse are roughly on par with the rest of the population, at about 10 percent. For prescription drugs, abuse rates for doctors in several specialties are estimated to be even higher—not surprising given their access to addictive medications.

One doctor, who cared for patients while surreptitiously taking large doses of prescription narcotics, wrote in the *Contra Costa Times* that "I held patients' lives in my hands when I practiced medicine while high on narcotic drugs for 3½ years. I made errors." Systematic studies connecting medical errors to drug abuse are hard to do, in part because physicians are skilled at hiding their addiction, yet experts who have culled through case data agree that the danger exists. The inspector general for the U.S. Health and Human Services Department is one of them. Earlier this year he called for mandatory random drug testing for all health care workers with access to drugs.

The idea is a good one. We require such testing of airplane pilots, train conductors, truck drivers and others whose impaired behavior could endanger many lives.

In November, California could become the first state to mandate that crucial level of safety in health care. Voters will consider a ballot initiative that includes a requirement for random drug testing for physicians. The bill may not pass, because it also contains medical malpractice initiatives that face strong opposition. But regardless of what Californians decide, their steps to address drug abuse among health care workers should be emulated across the country.

Expecting health care professionals to police themselves has not worked. One 2010 study published in *JAMA* surveyed almost 2,000 physicians and found that 17 percent said they personally and directly knew an impaired or incompetent physician in the prior three years—yet only 67 percent of those physicians who knew of a colleague's problems reported that person to a relevant authority.

The new California initiative, if made into law, would require the state medical board to oversee a drug- and alcohol-testing program. Random tests would be carried out by doctors' hospitals. Physicians also would be tested when suspected of substance abuse or after an unexpected patient death or serious injury occurred. In addition, doctors would have to report colleagues to the medical board if they suspected drug or alcohol impairment on the job. If doctors tested positive, their medical licenses would be suspended, pending investigation.

We know testing can work, and it may act as an effective deterrent. Since 2004 at Massachusetts General Hospital, a random drug-testing requirement has been in place for anesthesiology residents. During the six years before the program started, there were four substance abuse incidents (uncovered after suspicious behavior prompted for-cause drug testing). But in the 10 years since testing began, not a single resident has tested positive.

Testing, however, should be just the beginning. The goal is not to punish people but to protect patients and get health care providers into treatment so they can safely get back to work. Positive test results should not have to cost physicians their careers: a positive test should lead to a referral to physician health programs that work with state agencies. Most states have such programs, which monitor participants, evaluate needs and direct them to treatment rather than disciplinary action. A 2008 study published in the *BMJ* tracked 802 doctors monitored by these programs for five years and found that about 65 percent remained free of substance abuse. Some physicians asked to continue being monitored as a guard against relapse. The one-out-of-three relapse rate makes it clear that a continued-testing program is essential to help catch backsliders.

There should be better efforts to aid troubled health care workers when they need it and stronger checks to rein in unnecessary access to prescription opioids and to track controlled substances. But such actions will not happen overnight, and drug testing is a good start. If we expect our train and truck drivers to be sober when they clock in, we should expect nothing less from those who follow the Hippocratic credo to, above all, do no harm. SA

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Illustration by Neil Webb

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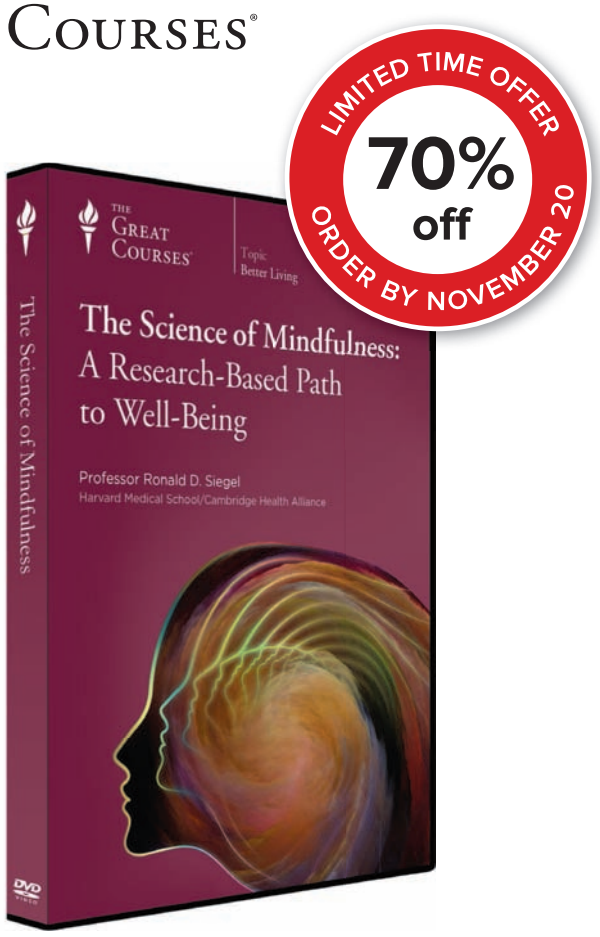

Meld Ancient Wisdom with Modern Science

Many problems that we face—such as depression, compulsive and addictive behaviors, chronic pain, and stress and anxiety— stem from the human brain's hardwired tendency to seek pleasure and avoid pain. For thousands of years, people have used mindfulness practices to deal effectively with life challenges such as these. And we are now in the midst of an explosion of scientific research, demonstrating that mindfulness practice changes the function and structure of the brain.

In these 24 fascinating lectures, Professor Ronald D. Siegel, a clinical psychologist at Harvard Medical School, reveals the science behind mindfulness in compelling detail, and demonstrates its application to a wide range of issues—psychological, social, and medical. Learn how these techniques can radically transform the mind, the heart, and the experience of everyday life—joining ancient wisdom practices and scientific methodology in forging new possibilities for living.

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Commentary on science in the news from the experts

Jonathan Zittrain is George Bemis Professor of Law, a professor of computer science and a director of the Berkman Center for Internet & Society at Harvard University. He is author of *The Future of the Internet—And How to Stop It* (Yale University Press, 2008). Zittrain serves on the board of advisers for *Scientific American*.

The Case for Kill Switches

Smart technology might have disarmed ISIS without bombs or bullets

This summer the Iraqi insurgent group ISIS captured the city of Mosul—and along with it, three army divisions' worth of U.S.-supplied equipment from the Iraqi army, including Humvees, helicopters, antiaircraft cannons and M1 Abrams tanks. ISIS staged a parade with its new weapons and then deployed them to capture the strategic Mosul Dam from outgunned Kurdish defenders. The U.S. began conducting air strikes and arming the Kurds to even the score against its own weaponry.

It is past time that we consider whether we should build in a way to remotely disable such dangerous tools in an emergency. The theft of iPhones plummeted this year after Apple introduced a remote "kill switch," which a phone's owner can use to make sure no one else can use his or her lost or stolen phone. If this feature is worth putting in consumer devices, why not embed it in devices that can be so devastatingly repurposed—including against their rightful owners, as at the Mosul Dam?

An immediate worry is whether a kill switch might not work when it is supposed to. An even bigger concern is that it might work when it is not supposed to—for example, if it is hacked by an enemy. There is a reason tank operators start their vehicles with a switch requiring no ignition key or code: it is so easy to misplace or become separated from keys on a battlefield that the risk of unauthorized access is worth bearing.

But ignition keys represent the best technology of 1949. Today there are many more possibilities. At least one foreign policy analyst has suggested incorporating GPS limitations into Stinger surface-to-air missiles to assist the Free Syrian Army in its defenses against air attack while ensuring that the missiles are useless outside that theater of conflict. More simply, any device with onboard electronics, such as a Stinger or a modern tank, could have a timed expiration; the device could operate after the expiration date only if it receives a coded "renew" signal from any of a number of overhead satellites. The renewal would take effect as a matter of course—unless, say, the weapons were stolen. This fail-safe mechanism could be built using basic and well-tested digital signature-and-authentication technologies. One example is the permissive action link devices by which American nuclear weapons are secured; these devices allow the weapons to be activated only when specific codes are shared. Another involves the protocols by which remotely operated drones are safeguarded against digital hijacking.

The simplest way to use a kill switch would be to place it in the hands of the weapons' original recipients. With a kill switch, the current Iraqi government could have disabled the bristling trophies of ISIS's post-Mosul parade. A more radical use of a kill switch would be to leave it in the hands of the weapons-providing government. This would turn weaponry into a service rather than a product. Many arms purchasers would no doubt turn elsewhere, but others might find the U.S. to be the only willing source. Some arms deals, including those between the U.S. and Israel, have already been subject to agreed-on limitations. A kill switch would represent a powerful enforcement mechanism.

For those who believe the United Nations Security Council might have a meaningful role to play in advancing world security, imagine if a kill switch reposed there, capable of being triggered only if the council voted to use it. In the most common case, a resolution to activate a kill switch would simply be vetoed by disagreeing member states. But in those cases where world opinion is sufficiently unified—as with the current Security Council arms embargo against al Qaeda (and by explicit association, ISIS)—the council's edict could have bite, with no military action necessary.

Implementation is everything, and policy makers must think about how a kill-switch strategy could fail. For example, because kill switches would provide assurance that weapons can be controlled down the line, they could lead to more weapons transfers happening overall. If those kill switches were easy to circumvent, we would be worse off than before.

Today, however, we are making a conscious choice to create and share medium and heavy weaponry while not restricting its use. This choice has very real impacts. If they can save even one innocent life at the end of a deactivated U.S. barrel, kill switches are worth a serious look. SA

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Illustration by Edel Rodriguez

nature video

A picture of health

in association with SCIENTIFIC AMERICAN™




Nature Video presents four films from the 2014 Nobel Laureate Meeting in Lindau.

View the films on nature.com/lindau/2014*
and on iTunes and the *Nature Video* channel on YouTube

Reporter Lorna Stewart travels to the German island of Lindau to meet 600 of science's brightest young minds and 37 rock stars – Nobel laureates. In a series of four films, Lorna asks some of the most profound questions in medicine. In one film, superstar statistician Hans Rosling helps Lorna get to grips with the realities of an ageing global population. In other films, Lorna delves into the past 40 years of cancer research, wonders if we'll ever eliminate side effects when we take medication, and receives a reality check on the battle against HIV.

Access the Lindau Video site on your smartphone

*Published weekly from the 24 September - 15 October 2014

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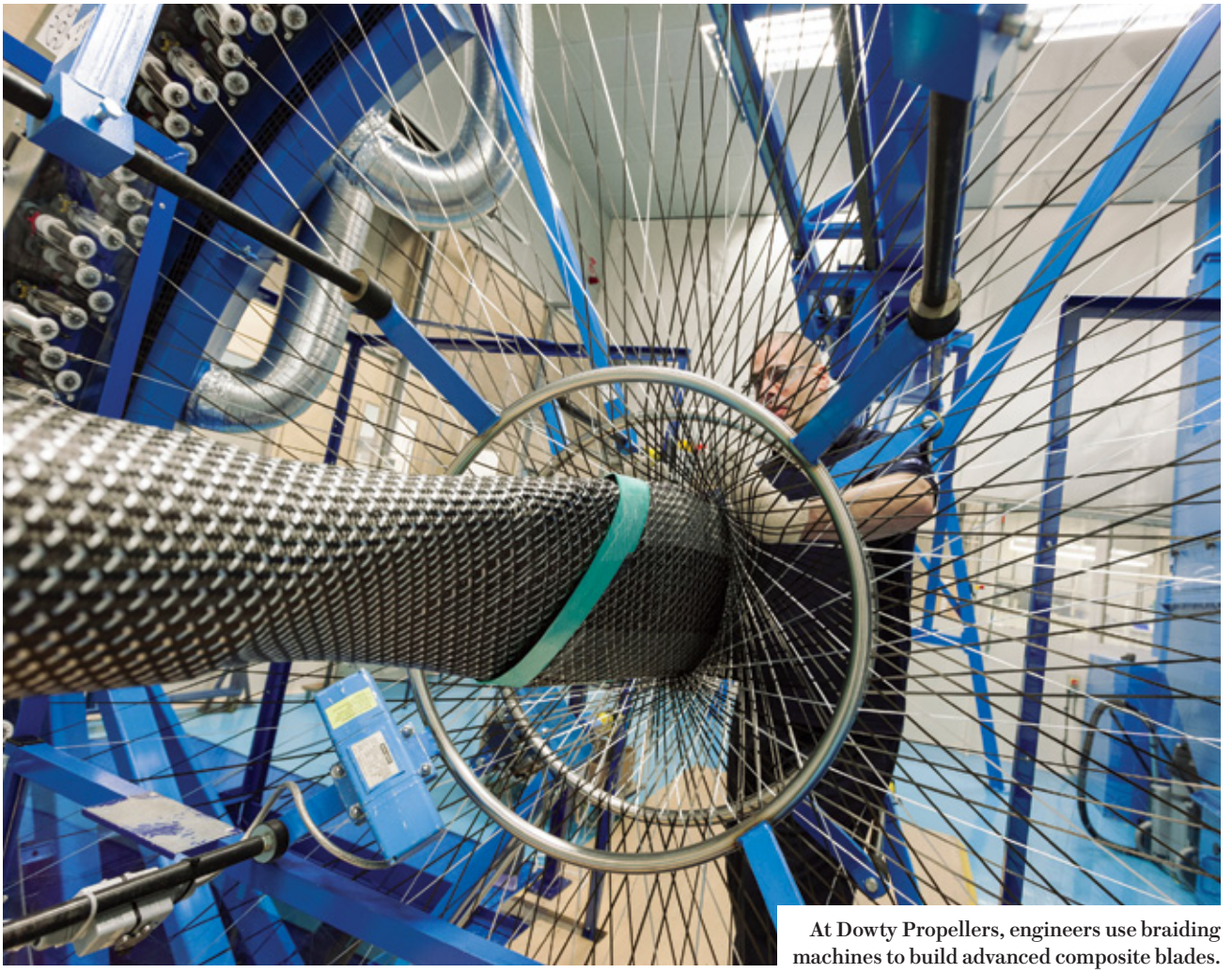

At Dowty Propellers, engineers use braiding machines to build advanced composite blades.

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ENGINEERING

Return of the Propeller

The demand for shorter, cheaper flights is driving new research into turboprops

A century ago the debut of propeller-driven aircraft kicked off a global aerospace technology boom. But after World War II, the economics of flight changed to favor planes that could go faster and farther, and so research attention shifted to jets. While turbofan technology advanced apace, propellers remained much the same. In the past 10 years, however, fuel prices and demand for regional air travel have risen. As a result, airlines are once again looking to smaller, more efficient planes to handle shorter routes. With the turboprop back in favor, engineers in the lab are now giving the technology a second look. By the end of the decade a new generation of prop-driven aircraft technologies will be poised to take wing.

Turboprop planes accounted for roughly half of the 20- to 99-seat passenger aircraft delivered to airlines in 2013, according to market research conducted by Canadian plane maker Bombardier—parity that has not existed since the 1990s. Demand has risen because on flights less than about 500 nautical miles, turboprops are far more fuel-efficient than turbofans, which fly at their best only after they have made the long climb to their much higher cruising altitudes. But in exchange for their efficiency, traditional turboprops sacrifice airspeed and generate noise and vibrations that compromise passenger comfort. For airlines competing over customer experience as much as price (and acutely aware of passengers' perceptions of propeller-driven

Continued on page 21

For people with a higher risk of stroke due to
Atrial Fibrillation (AFib) not caused by a heart valve problem

ELIQUIS® (apixaban) is a prescription medicine used to reduce the risk of stroke and blood clots in people who have atrial fibrillation, a type of irregular heartbeat, not caused by a heart valve problem.

IMPORTANT SAFETY INFORMATION:

- **Do not stop taking ELIQUIS for atrial fibrillation without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke.** ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.
- **ELIQUIS can cause bleeding, which can be serious,** and rarely may lead to death.
- **You may have a higher risk of bleeding if you take ELIQUIS and** take other medicines that increase your risk of bleeding, such as aspirin, NSAIDs, warfarin (COUMADIN®), heparin, SSRIs or SNRIs, and other blood thinners. **Tell your doctor about all medicines, vitamins and supplements you take.** While taking ELIQUIS, you may bruise more easily and it may take longer than usual for any bleeding to stop.
- Get medical help right away if you have any of these signs or symptoms of bleeding:
  - unexpected bleeding, or bleeding that lasts a long time, such as unusual bleeding from the gums; nosebleeds that happen often, or menstrual or vaginal bleeding that is heavier than normal
  - bleeding that is severe or you cannot control
  - red, pink, or brown urine; red or black stools (looks like tar)
  - coughing up or vomiting blood or vomit that looks like coffee grounds
  - unexpected pain, swelling, or joint pain; headaches, feeling dizzy or weak
- **ELIQUIS is not for patients with artificial heart valves.**
- **Spinal or epidural blood clots (hematoma).** People who take ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis).

I was taking warfarin. But ELIQUIS was a better find.

I TAKE ELIQUIS® (apixaban) FOR 3 GOOD REASONS:

1. ELIQUIS reduced the risk of stroke better than warfarin.
2. ELIQUIS had less major bleeding than warfarin.
3. Unlike warfarin, there's no routine blood testing.

ELIQUIS and other blood thinners increase the risk of bleeding which can be serious, and rarely may lead to death.

Ask your doctor if ELIQUIS is right for you.

This risk is higher if, an epidural catheter is placed in your back to give you certain medicine, you take NSAIDs or blood thinners, you have a history of difficult or repeated epidural or spinal punctures. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

- **Before you take ELIQUIS,** tell your doctor if you have: kidney or liver problems, any other medical condition, or ever had bleeding problems. Tell your doctor if you are pregnant or breastfeeding, or plan to become pregnant or breastfeed.
- **Do not take ELIQUIS if you** currently have certain types of abnormal bleeding or have had a serious allergic reaction to ELIQUIS. A reaction to ELIQUIS can cause hives, rash, itching, and possibly trouble breathing. Get medical help right away if you have sudden chest pain or chest tightness, have sudden swelling of your face or tongue, have trouble breathing, wheezing, or feeling dizzy or faint.

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

Please see additional Important Product Information on the adjacent page.

Individual results may vary.

Visit ELIQUIS.COM
or call 1-855-ELIQUIS

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IMPORTANT FACTS about ELIQUIS® (apixaban) tablets

℞ ONLY

The information below does not take the place of talking with your healthcare professional. Only your healthcare professional knows the specifics of your condition and how ELIQUIS may fit into your overall therapy. Talk to your healthcare professional if you have any questions about ELIQUIS (pronounced ELL eh kwiss).

What is the most important information I should know about ELIQUIS (apixaban)?

For people taking ELIQUIS for atrial fibrillation: Do not stop taking ELIQUIS without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke. ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.

ELIQUIS can cause bleeding which can be serious, and rarely may lead to death. This is because ELIQUIS is a blood thinner medicine that reduces blood clotting.

You may have a higher risk of bleeding if you take ELIQUIS and take other medicines that increase your risk of bleeding, such as aspirin, nonsteroidal anti-inflammatory drugs (called NSAIDs), warfarin (COUMADIN®), heparin, selective serotonin reuptake inhibitors (SSRIs) or serotonin norepinephrine reuptake inhibitors (SNRIs), and other medicines to help prevent or treat blood clots.

Tell your doctor if you take any of these medicines. Ask your doctor or pharmacist if you are not sure if your medicine is one listed above.

While taking ELIQUIS:

- you may bruise more easily
- it may take longer than usual for any bleeding to stop

Call your doctor or get medical help right away if you have any of these signs or symptoms of bleeding when taking ELIQUIS:

- unexpected bleeding, or bleeding that lasts a long time, such as:
  - unusual bleeding from the gums
  - nosebleeds that happen often
  - menstrual bleeding or vaginal bleeding that is heavier than normal
- bleeding that is severe or you cannot control
- red, pink, or brown urine
- red or black stools (looks like tar)
- cough up blood or blood clots
- vomit blood or your vomit looks like coffee grounds
- unexpected pain, swelling, or joint pain
- headaches, feeling dizzy or weak

ELIQUIS (apixaban) is not for patients with artificial heart valves.

Spinal or epidural blood clots or bleeding (hematoma). People who take a blood thinner medicine (anticoagulant) like ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis). Your risk of developing a spinal or epidural blood clot is higher if:

- a thin tube called an epidural catheter is placed in your back to give you certain medicine
- you take NSAIDs or a medicine to prevent blood from clotting
- you have a history of difficult or repeated epidural or spinal punctures
- you have a history of problems with your spine or have had surgery on your spine

If you take ELIQUIS and receive spinal anesthesia or have a spinal puncture, your doctor should watch you closely for symptoms of spinal or epidural blood clots or bleeding. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

What is ELIQUIS?

ELIQUIS is a prescription medicine used to:

- reduce the risk of stroke and blood clots in people who have atrial fibrillation.
- reduce the risk of forming a blood clot in the legs and lungs of people who have just had hip or knee replacement surgery.

It is not known if ELIQUIS is safe and effective in children.

Who should not take ELIQUIS (apixaban)?

Do not take ELIQUIS if you:

- currently have certain types of abnormal bleeding
- have had a serious allergic reaction to ELIQUIS. Ask your doctor if you are not sure

What should I tell my doctor before taking ELIQUIS?

Before you take ELIQUIS, tell your doctor if you:

- have kidney or liver problems
- have any other medical condition
- have ever had bleeding problems
- are pregnant or plan to become pregnant. It is not known if ELIQUIS will harm your unborn baby
- are breastfeeding or plan to breastfeed. It is not known if ELIQUIS passes into your breast milk. You and your doctor should decide if you will take ELIQUIS or breastfeed. You should not do both

Tell all of your doctors and dentists that you are taking ELIQUIS. They should talk to the doctor who prescribed ELIQUIS for you, before you have **any** surgery, medical or dental procedure. **Tell your doctor about all the medicines you take, including** prescription and over-the-counter medicines, vitamins, and herbal supplements. Some of your other medicines may affect the way ELIQUIS works. Certain medicines may increase your risk of bleeding or stroke when taken with ELIQUIS.

How should I take ELIQUIS?

Take ELIQUIS exactly as prescribed by your doctor. Take ELIQUIS twice every day with or without food, and do not change your dose or stop taking it unless your doctor tells you to. If you miss a dose of ELIQUIS, take it as soon as you remember, and do not take more than one dose at the same time. **Do not run out of ELIQUIS (apixaban). Refill your prescription before you run out.** When leaving the hospital following hip or knee replacement, be sure that you will have ELIQUIS available to avoid missing any doses. **If you are taking ELIQUIS for atrial fibrillation, stopping ELIQUIS may increase your risk of having a stroke.**

What are the possible side effects of ELIQUIS?

- See **"What is the most important information I should know about ELIQUIS?"**
- ELIQUIS can cause a skin rash or severe allergic reaction. Call your doctor or get medical help right away if you have any of the following symptoms:
  - chest pain or tightness
  - swelling of your face or tongue
  - trouble breathing or wheezing
  - feeling dizzy or faint

Tell your doctor if you have any side effect that bothers you or that does not go away.

These are not all of the possible side effects of ELIQUIS. For more information, ask your doctor or pharmacist.

Call your doctor for medical advice about side effects. You may report side effects to FDA at 1-800-FDA-1088.

This is a brief summary of the most important information about ELIQUIS. For more information, talk with your doctor or pharmacist, call 1-855-ELIQUIS (1-855-354-7847), or go to www.ELIQUIS.com.

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March 2014
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Continued from page 17

aircraft as passé), the propeller technology of the last century will not do.

Among those paving the way for a new generation of turboprops, General Electric Aviation's Dowty Propellers is exploring anew the interactive effects among the propeller, engine nacelle and aircraft wing. Using computational fluid dynamics software that was not available even a few years ago, engineers at the Gloucester, England–based firm can now analyze data on each blade individually. But they are not only designing blades with new efficiency-enhancing shapes. They are also rethinking the layout of the propeller as a whole.

"The computational power that's available now has really made the difference," says Dowty's Jonathan Chestney. "It's an exciting time for us. We're able to see much more detail, like a scientist who just got a microscope for the first time."

Dowty engineers are currently exploring two novel spacing ideas for eight-blade propellers. One positions the blades unequally around the circumference of the propeller hub; the other staggers the blades axially, with four blades mounted farther forward on the hub than the others. These spacing schemes break up and change the audible frequencies created in flight. Dowty is in the midst of testing the corresponding cabin sounds on volunteers to see which ones they prefer.

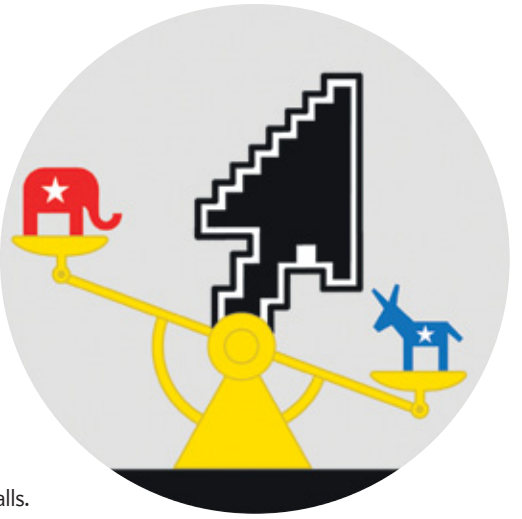
Dowty's research is not taking place in a vacuum. Advanced propellers will appear in the next-generation helicopters that the U.S. Department of Defense wants and in upcoming unmanned aerial vehicles, says aerospace engineer Lakshmi Sankar of the Georgia Institute of Technology. As such, research is taking place across the industry and even across disciplines. Computational fluid dynamics research on propellers conducted at places such as the NASA Glenn Research Center and Georgia Tech are feeding into designs coming out of suppliers, including Dowty and Charlotte, N.C.–based UTC Aerospace Systems.

Novel designs are not far from the tarmac. Says Dowty's Chestney, "We expect to see some key players going public with new aircraft designs in the next couple of years." —*Clay Dillow*

STATISTICS

Pollsters' Dilemma

Landlines are dying—and taking phone-based opinion polling with them. Where will election forecasters turn next?



No one answers the phone anymore. Back in the Clinton days, pollsters could collect voter opinions from about one in three calls. Today it is fewer than one in 11. Blame disappearing landlines—fewer than half of U.S. households regularly used one in 2013—as well as cell-phone caller ID. Yet even as response rates plummet and costs of chasing mobile users soar, most data-driven election predictions still rely on phone-poll results. Even Nate Silver's FiveThirtyEight models, which perfectly predicted 2012 presidential race outcomes in all 50 states and the District of Columbia, hinge largely on phone surveys. So researchers are now hunting for alternative sources of voter data—and finding them in unlikely places. —*Regina Nuzzo*

ONLINE REWARDS

At YouGov, volunteers answer online surveys in exchange for gift cards. When the *New York Times* and CBS News announced in July that they would rely on YouGov for the November midterm elections, traditional pollsters were aghast. Opt-in surveys break the cardinal rule of polling: respondents should be a random sample of the population. But the global polling firm claims its demographic profiles rival those of even the best phone polls. Case in point: YouGov's prediction for Obama's two-party 2012 vote share was off by only one percentage point. Gallup's error was nearly three times as high—and predicted the wrong candidate.

XBOX

Video gamers are hardly a cross section of voting America. So when more than 340,000 Microsoft Xbox users—mostly male millennials—replied to mini surveys before the 2012 election, researchers at Microsoft and Columbia University mined the data with new statistical techniques that were designed to deal with nonrepresentative data. It worked. Not only could the analyses predict Obama's vote share within 0.6 percentage point, their estimates for voting preferences of demographic subgroups—women older than 64, say—were a hair's breadth away from exit polls. More mini surveys are coming soon to other Microsoft platforms.

SOCIAL MEDIA

Some forecasting researchers have turned to eavesdropping. Analyzing candidates' Facebook friends has hinted at election results in New Zealand; Flickr's geo-tags showed the spread of 2008 U.S. presidential campaigns; and Twitter's data have predicted elections worldwide. In 2013 a project at Raytheon BBN Technologies analyzing 13 billion tweets in Latin America—funded by the U.S. intelligence community—found the number of candidate mentions could predict the winner's vote share with errors as low as 0.6 percentage point. Adding in data from YouTube and Google Trends bolstered accuracy even more.

GAMBLING

Ask voters who they *think* will win, and you will get better results than asking whom they are voting for. Why? The former also captures the election zeitgeist—friends' opinions, pundits' rants, and more. Betting pools do, too. At online prediction markets, people buy shares in election outcomes; higher market prices reveal a stronger combined belief in the outcome. Although election gambling is illegal for U.S. citizens, a few international futures markets such as the U.K.'s Betfair and bitcoin-driven Predictious are thriving. Analyses of Intrade's price history before the company was shuttered predicted Obama's 2008 win with excellent estimates in contested races—and even more accurately than Nate Silver's.

Illustrations by Thomas Fuchs


Swainson's thrushes migrate along routes influenced by their genetics.

BIOLOGY

Which Direction Home?

Some migrating birds get conflicting instructions from Mom and Dad

Every autumn migrating birds in the Northern Hemisphere fly south to escape the cold. If we humans were to make such a journey, we would need a map. But each bird has its route stored at least partially in its genes. Rather than relying solely on external cues, it has an innate flight plan.

Most individuals within a single population follow the same migration path, taking advantage of favorable winds and optimal topography. But some birds are hybrids; their parents come from different populations and so have different paths. How do the birds choose?

Early experiments suggested that hybrids take an intermediate route relative to the ones their parents follow. The tests used laboratory-raised birds whose preferences were assessed using a cage designed to record the direction the birds wanted to fly. "These studies were fantastic, but what we really needed to do was follow [wild] birds over an entire year," says Kira Delmore, a graduate student at the University of British Columbia.

Delmore and her colleagues outfitted 97 wild Swainson's thrushes with tiny GPS trackers. Some of the subjects belonged to a subspecies that flies along the western coast of North America to winter in Mexico, Guatemala and Honduras. Others belonged to an inland subspecies that flies through east-central North America to Colombia and Venezuela. The hybrids of the group were born in a small area where the two populations overlap in the coastal mountains of western Canada.

The team recovered useful data from 21 of the birds and found that some hybrids flew intermediate routes compared with their parents, confirming the earlier lab findings. Others took mixed routes, following one parent's path in spring and then switching to the other's in fall. Still others stuck with the route of one parent. Intriguingly, some of those hybrids that took intermediate routes also settled in intermediate destinations. "This is the first paper to show that both [the] route and destination of hybrids can be intermediate," says Bridget J. Stutchbury, a bird researcher at York University in Toronto. The study was published in October in *Ecology Letters*.

Delmore suspects that hybrids may have a harder time surviving because they fly inefficient routes over arid or mountainous terrain: in this case, the American Southwest. Researchers will have to run another tracking study to determine whether that is the case. If Delmore's hunch turns out to be true, then migration pathways may be a driving factor of bird speciation. For the Swainson's thrushes, should the hybrids have trouble surviving their trips, then the coastal and inland groups might eventually evolve into separate species. —*Jason G. Goldman*

STEVE GETTLE *Getty Images*

COMMENT AT ScientificAmerican.com/nov2014

CLIMATE

When Evidence Melts Away

Climate scientists race to sample cave ice before it's too late

Scărişoara Ice Cave, Romania

COURTESY OF AUREL PERSOIU

On a recent visit to Crystal Ice Cave in Idaho, climate and cave researchers had to wade through frigid, knee-deep water to reach the ice formations that give the cave its name. Cavers are good-humored about the hardships of underground exploration, but this water was chilling for more than one reason: it was carrying away some of the very clues they had come to study.

Ice is an invaluable source of information about the earth's past. Pollen trapped in ice from polar ice caps and mountaintop glaciers documents plant life up to 1.5 million years ago, and gas bubbles and water isotopes reveal glimpses of ancient temperatures.

Polar ice samples cannot necessarily reveal what the climate was like in, say, New Mexico or other temperate regions, however. So a decade ago a small group of researchers began meeting to discuss the potential of cave ice, some of which is more than 3,000 years old. Since then, studies have confirmed that cave ice can illuminate some questions about how lower altitudes and latitudes responded to climate swings. But by this summer, when the scientists found themselves wading through the meltwater in Crystal Ice Cave during their biennial workshop, the main question had changed from what the ice could tell them to how to retrieve enough before it disappeared.

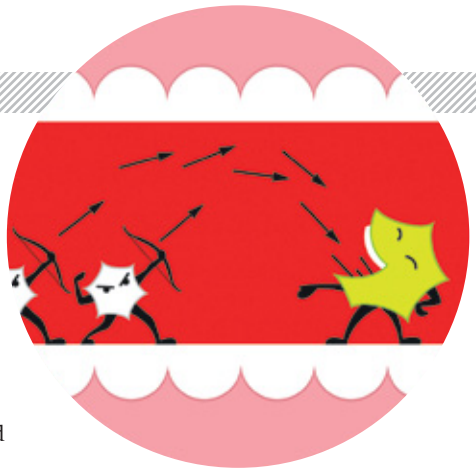
Thus far researchers have not won much funding for long-term studies of ice caves. Part of the reason is that obtaining a sample is a massive, expensive effort, requiring intense drilling, helicopters and refrigerated vans. And geochemist Zoltán Kern of the Hungarian Academy of Sciences in Budapest notes that he understands funders' qualms because scientists have not yet figured out how to convert complicated cave ice data into tidy climate records. But this much is clear, says George Veni, director of the National Cave and Karst Research Institute in Carlsbad, N.M.: before the ice melts, "the main thing is to try and collect as much of it as possible."

—Lucas Laursen

KNOW THE JARGON

Keystone pathogen:

(*n.*) A microorganism that, relative to its numbers, plays a disproportionately large role in transforming a benign microbial community into one that can cause disease.



The vast majority of microbes that live in and on our bodies do not put our health at risk, but many can cause problems if their populations grow out of control. So the immune system keeps their numbers in check, culling resident bacteria here and there.

A few microbial species have found ways to sabotage the immune system and skew the balance of power in their favor. Take *Porphyromonas gingivalis,* a mouth-dwelling bacterium that has long been the prime suspect behind gum disease. Even in small numbers, *P. gingivalis* can stop white blood cells from producing certain chemicals that kill bacteria. Without these chemicals to restrict their growth, all the bacterial populations in the mouth—including those that had been contributing to a healthy ecosystem—grow explosively, causing tissue damage known as gingivitis.

In two recent studies, a team of University of Pennsylvania researchers led by dental microbiologist George Hajishengallis figured out the mechanism behind *P. gingivalis*'s subterfuge. Building on that knowledge, the scientists discovered that blocking a key chemical signal returned the microbial communities in the mouths of mice to normal.

The standard care for gingivitis is a professional tooth cleaning and more flossing, which temporarily reduce bacterial numbers but do not restore white blood cells' ability to kill. As such, dentists cannot do much to treat recurring inflammation. The team says its findings could lead to future treatment options.

Keystone pathogens may be the culprits behind other chronic inflammatory diseases, too, Hajishengallis says. But to pin down links, scientists need to better understand how keystone bacteria manipulate the checks and balances that allow humans to live in harmony with trillions of microbes. *—Diana Crow*

TECHNOLOGY

The Ball That Hovers

Physics-flouting design could change sports dynamics

In many sports, mastery of the ball is crucial to success. But what happens if the ball disobeys the laws of physics? Researchers at the Sony Computer Science Laboratory (CSL) and the University of Tokyo are working on just such a device: HoverBall.

HoverBall is a 90-millimeter-wide quadcopter enclosed in a cage a bit bigger than a bocce ball. It is designed to hang in the air, change location and modify its behavior during play. The 10-gram, battery-powered device can fly for five minutes at a time, and although the most recent version relies on a remote control to guide its four rotors, future iterations might be programmed to operate autonomously. HoverBall's surprise midair maneuvers introduce a new level of spontaneity to game play via "artificial physical laws" that follow "imaginary dynamics," the researchers said in a study they presented earlier this year at the Augmented Human Conference in Kobe, Japan.

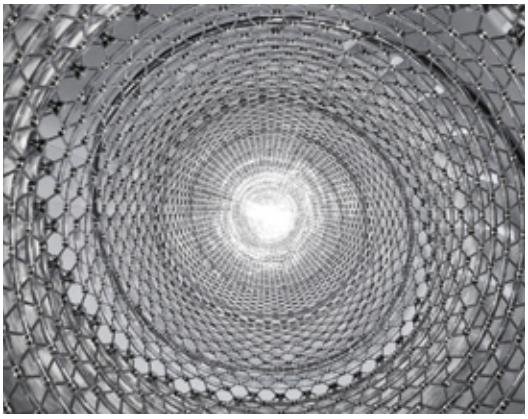
COURTESY OF SONY CSL

Sony's HoverBall can travel up to five meters a second.

Beyond introducing erratic flight, the Sony team would like the ball to compensate for differences in player abilities and therefore make games more inclusive for children, the elderly and people with physical disabilities, according to Jun Rekimoto, Sony CSL deputy director.

HoverBall is a long way from store shelves, though. The quadcopter needs plenty of air intake to fly, which is why it currently has an open cage, but that design limits its durability and potential for use in contact sports. The researchers are considering options for a rugged version, including additional powerful rotors that could handle a heavier, more solid ball with a bigger battery and tougher surface.

—Larry Greenemeier



ARCHITECT:
Eva Jiricna

STRUCTURAL ENGINEERING FIRM:
Techniker

HEIGHT:
62 feet

CANTILEVERED STEPS:
104

CONCRETE SHRINKAGE:
Up to 0.15 percent

HIGH-PERFORMANCE CONCRETE SHRINKAGE:
Less than 0.06 percent

ENGINEERING

Snaking Stairs

The Miles Stair is a 12-foot-wide helix of white concrete that winds through five stories of Somerset House, a cultural center in London. Staircases typically use surrounding walls for support, but the Miles Stair relies on a core built from a latticework of lightweight stainless steel. Engineers managed to pull off this improbable structure because the steps are built from high-performance concrete, which is stronger, lighter and more stable than regular concrete.

Mixed with steel or nylon fibers, high-performance concrete is almost as strong as cast iron. It was invented to fill in gaps in large concrete works such as bridges, but within the past five years, engineers have increasingly used it to build entire structures. It also does not shrink over time like ordinary concrete does, so "what you cast is what you get," says Matthew Wells, a project representative at Techniker, the London-based firm that built the staircase.

The Miles Stair is a nominee in the Institution of Structural Engineers' Structural Awards, which recognizes projects for their engineering, elegance and economy. The winner will be announced on November 14, but to Wells, the staircase has already proved itself: there is an elevator, but hardly anyone uses it.

—Kate Baggaley

COURTESY OF RICHARD DAVIES

COMMENT AT ScientificAmerican.com/nov2014

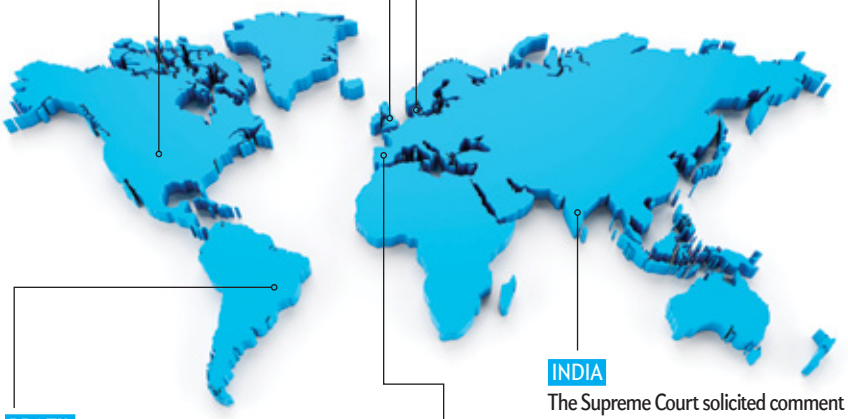
IN THE NEWS

Quick Hits

U.S.
Elon Musk's SpaceX will build a commercial space launchpad in South Texas—the world's first. Scheduled completion date: 2016.

U.K.
Starting in January 2015, public roads will be open to driverless cars.

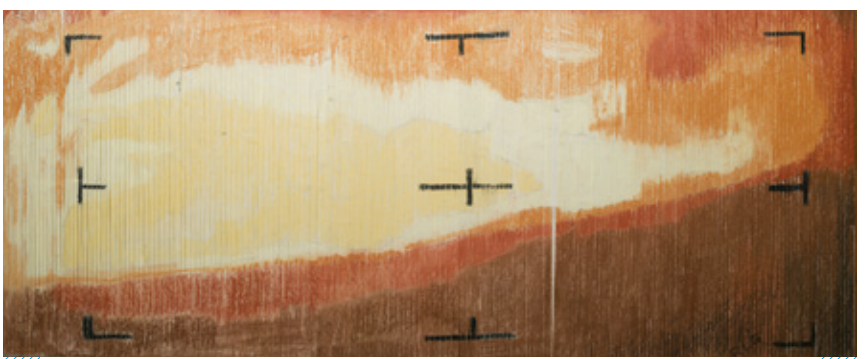
DENMARK
Surpassing coal and natural gas, wind power is now the cheapest form of electricity in the country.



BRAZIL
Regulators are considering approval of a genetically modified eucalyptus tree. It would be the first transgenic tree with widespread commercial distribution.

INDIA
The Supreme Court solicited comment from its state governments to examine the right to die in terminally ill patients.

SPAIN
Manuel Linares, a physicist in his past, developed ice cream that changes colors when licked. He named it "Xamaleón."



ISTOCKPHOTO (*map*); COURTESY OF NASA/JPL AND DAN GOODS (*Mars*)

WHAT IS IT?

NASA's Mariner 4 completed the first successful flyby of Mars in the summer of 1965. The spacecraft had a camera onboard to capture Martian vistas, but transmitting all the data to Earth was slow, taking 19 days. So while waiting for Earth-bound electronics to convert the data into fully processed images, Richard Grumm of the NASA Jet Propulsion Laboratory decided to take matters into his own hands. He stapled strips of paper with incoming pixel brightness values onto a wall and then hand-colored the numbers with corresponding pastels. When Grumm was finished, the lighter zone filling most of the frame (*above*) showed the bottom edge of Mars fading into the darkness of space. The paint-by-numbers panel became the first image of Mars based on data collected by an interplanetary probe, as well as the first close-up image of the planet broadcast on television. In total, the mission delivered 21 complete images of the planet. This month marks the 50th anniversary of the launch of the Mariner 4 spacecraft, which took place on November 28, 1964. —*Jen Christiansen*

Homo floresiensis (*left*) had a brain a third as large as that of *Homo sapiens* (*right*), its contemporary.

COURTESY OF PETER BROWN

PALEOANTHROPOLOGY

Human or Hobbit?

The arguments over an ancient skeleton just won't go away

Old debates die hard in the study of human origins. In October 2004 paleoanthropologists announced the discovery of a new human species that lived as recently as 17,000 years ago on the Indonesian island of Flores. *Homo floresiensis,* also known as the hobbit, was an overnight sensation. Just over a meter tall, with a brain a third the size of our own, the creature was in many ways as primitive as our 3.2-million-year-old relative, Lucy. Yet it was a contemporary of *Homo sapiens* and apparently made some advanced stone tools, used fire and hunted large animals—activities associated with

brainier humans. Noting the conflicting observations, skeptics immediately countered that the bones belonged to a diseased *H. sapiens* individual, not a new species. And so began a battle over bones that continues to this day.

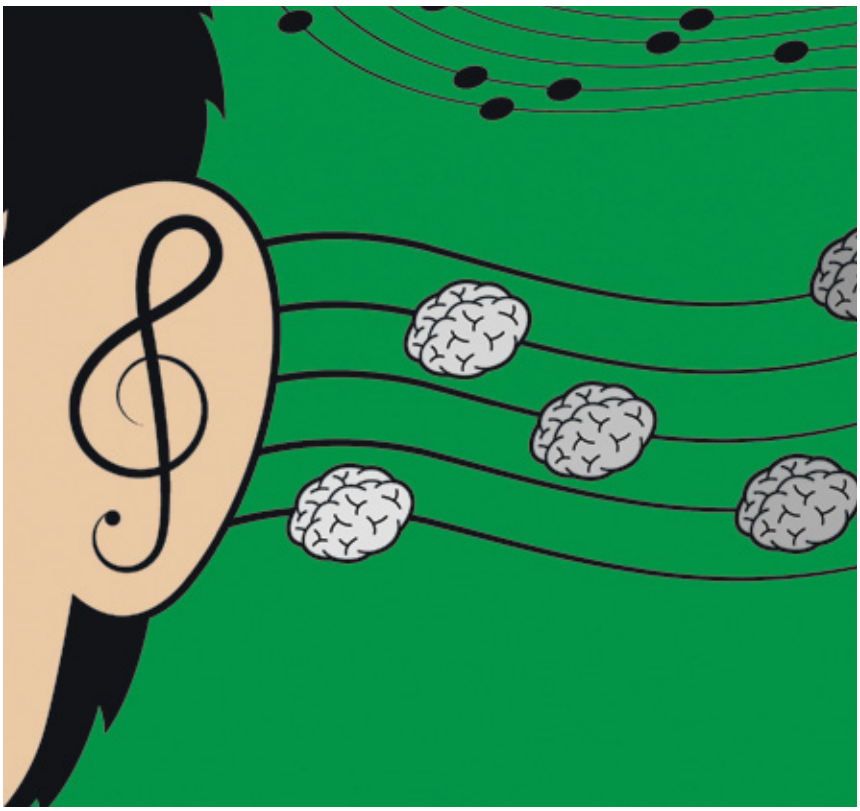
The latest attack comes from some of those same doubters. In a paper published in August in the *Proceedings of the National Academy of Sciences USA,* Maciej Henneberg of the University of Adelaide in South Australia and his colleagues argue that the bones of the most complete individual from the site, known as LB1, exhibit features indicative of Down syndrome. They base their argument on the small circumference of LB1's skull, among other traits.

Hobbit team members have been quick to reject the Down syndrome claim. William Jungers of Stony Brook University notes that there is no known case of Down syndrome (ancient or modern) in which an individual had a head circumference as small as LB1's. Nor do people with Down syndrome share LB1's other distinctive features, such as her projecting midface and thick braincase walls.

The possibility remains that the hobbit suffered from some other pathology that produced her strange features.

Still, even if the new work does not prove that LB1 had Down syndrome, the possibility remains that she suffered from some other pathology that produced her strange features. Biological anthropologist Thomas Schoenemann of Indiana University Bloomington, who studies brain evolution, notes that some proponents of *H. floresiensis* have insisted that scientists treat LB1 as representative of a new species unless a specific developmental anomaly can be matched to it. But that position "is simply not reasonable, given how odd [LB1] is with respect to the rest of the [human] fossil record," he says. "What we really need are more specimens and some trail of fossils that shows us how LB1 got to Flores" while retaining characteristics of australopithecines for more than a million years, Schoenemann observes. Ongoing excavation of the Flores site has yet to yield more small skulls. —*Kate Wong*

An in-depth report marking the 10-year anniversary of the Flores hobbit's unveiling is available October 23 at ScientificAmerican.com/nov2014/hobbits



COGNITION

Inside the Audience Studio

A new lab devoted to the science of performance opens

Music affects people deeply. At every stage of life, a large body of research shows, it has a profound impact on behavior and cognition. A new concert hall–cum-laboratory will be the first dedicated facility to examine music's effect on the brain. The Large Interactive Virtual Environment Lab (LIVElab) at McMaster University in Toronto, which opened this fall, will be an experimental space for neuroscientists, physiologists and psychologists to test hypotheses about performance, audience dynamics and musical improvisation. There are already several projects on the roster for this 96-seat venue. *—Katharine Gammon*

GROUP VIBE

Every culture in the world has music—one of the reasons that anthropologists consider it to be a defining characteristic of humanity. And experiencing music with others affects how people see one another: research shows that people who make music together are more likely to rate their collaborators as helpful or attractive. To learn more about how music impacts groups, LIVElab researchers will examine emotional arousal during performances with multiarray electroencephalography, heart rate monitors, and breath and sweat sensors. They will also use special infrared motion-capture cameras to observe the contagion of movement; for example, tracking how head bobbing spreads through the audience.

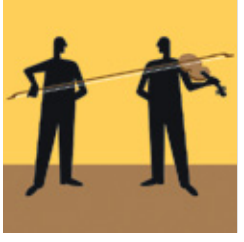
COMMENT AT ScientificAmerican.com/nov2014

THE ACOUSTICS OF LEARNING

Is working in a cubicle better for the brain? Does coffee-shop chatter help people retain new information? Using EEG and behavioral responses from students, LIVElab scientists will test what acoustic factors matter in a learning environment.

BETTER HEARING AIDS

Hearing aids are usually tested only under quiet conditions. At LIVElab, investigators will use an active acoustics system (which has 75 speakers and 28 microphones) to make the room sound dead or like a noisy restaurant, among other scenarios, and then measure how hearing ability changes with various aid models.



ALL TOGETHER NOW

Scientists want to know how brains synchronize using nonverbal interaction and how they make lightning-quick error corrections. With EEG and motion capture, LIVElab researchers plan to probe how musicians coordinate on a piece of music or how dancers' brains sync up for an important step.

SPACE

Catching Some Rays

An embattled cosmic-ray telescope gets a lift

Cosmic rays, traveling nearly at the speed of light, bombard Earth from all directions. The electrically charged particles are the most energetic component of cosmic radiation—yet no one knows where they come from.

Astrophysicists speculate that high-energy cosmic rays may have emerged from supermassive black holes in faraway galaxies or possibly from decaying particles from the big bang.

Whatever their origin, these high-energy rays crash into Earth's atmosphere about once per square kilometer per century. The impact produces an air shower of tens of billions of lower-energy particles that in turn excite nitrogen molecules in the atmosphere. The interactions produce ultraviolet fluorescence that lights up the shower's path. Scientists are trying to use such paths to measure the direction and energy of cosmic rays and reconstruct their trajectories back millions of light-years into space to pinpoint their source.

Seeing these extreme events is rare. Earth-based observatories can spot cosmic-ray collisions only if they occur directly above the detectors. The Pierre Auger Observatory in Argentina, which houses the world's largest cosmic-ray detector and covers an area roughly the size of Rhode Island, records about 20 extreme-energy particle showers a year.

Hoping to improve the odds of observing the rays, a team of scientists from 15 nations came together more than a decade ago and designed a cosmic-ray telescope for the International Space Station (ISS). On the Japanese Experimental Module, the Extreme Universe Space Observatory (JEM-EUSO) will record ultraviolet emissions with a wide-angle, high-speed video camera that points toward Earth. With such a large observation area, the camera will see more air showers.

The team originally hoped to launch JEM-EUSO in 2006. But troubles on Earth—the space shuttle *Columbia* disaster in 2003, then the Fukushima nuclear meltdown in 2011 and now the turmoil in Ukraine—have delayed its deployment until at least 2018.

The science, however, marches onward. In August the team launched a prototype of the telescope 38 kilometers into the stratosphere onboard a helium-filled balloon. For two hours, researchers followed below in a helicopter, shooting a pulsed UV laser and flashing LED into the telescope's field of view. The test was a success: the prototype detected the UV traces, which are similar to the fluorescence generated by extreme-energy cosmic-ray air showers. In 2016 astronauts will transport a bread-box-size prototype called Mini-EUSO to the ISS and see how it fares at the altitude of the full mission. *—Debra Weiner*

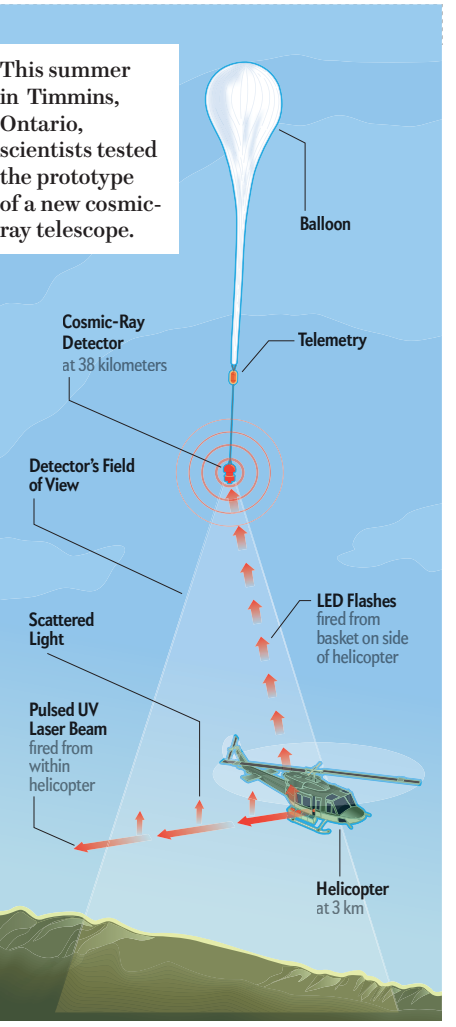
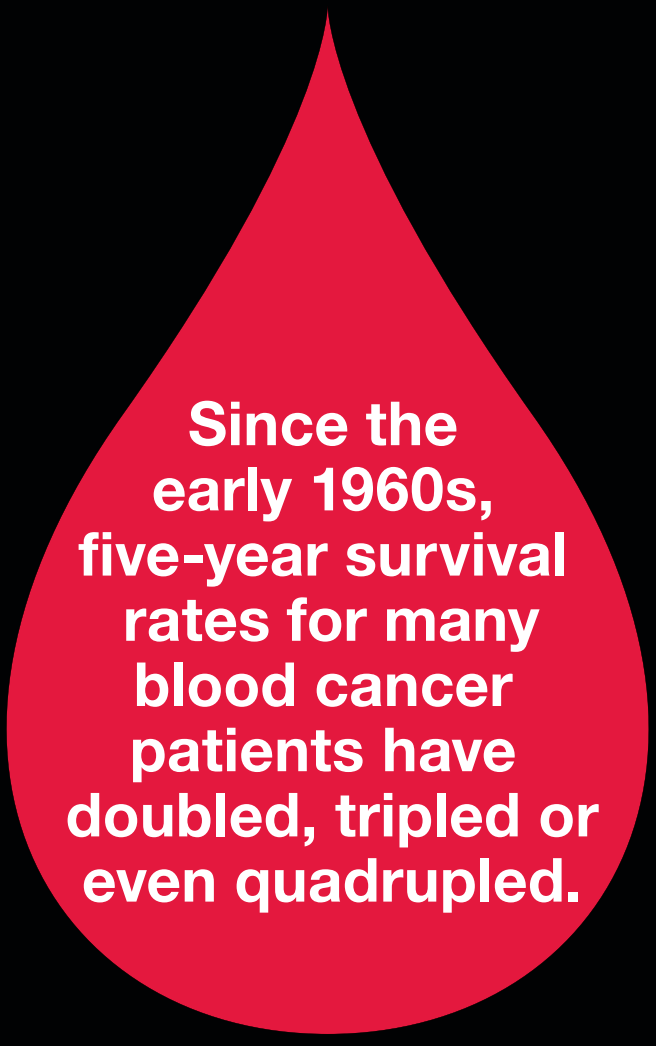


Illustration by Stephen Rountree

someday is today



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fighting blood cancers

James Levine is an endocrinologist who co-directs Obesity Solutions, a program of the Mayo Clinic in Scottsdale, Ariz., and Arizona State University. He is author of the book *Get Up!* (Palgrave Macmillan, 2014). (*Scientific American* and Palgrave Macmillan are affiliates.) Levine invented a treadmill desk but gains no financial benefit from sales.

Killer Chairs

Standing more, even at a desk job, could lower risk for obesity, illness and death, studies suggest

Chairs: we sit in them, work in them, shop in them, eat in them and date in them. Americans sit for most of their waking hours, 13 hours every day on average. Yet chairs are lethal.

This grim conclusion may surprise you, but 18 studies reported during the past 16 years, covering 800,000 people overall, back it up. In 2010, for example, the journal *Circulation* published an investigation following 8,800 adults for seven years. Those who sat for more than four hours a day while watching television had a 46 percent increase in deaths from any cause when compared with people who sat in front of the tube for less than two hours. Other researchers have found that sitting for more than half the day, approximately, doubles the risk of diabetes and cardiovascular problems. Overall, when you combine all causes of death and compare any group of sitters with those who are more active, sitters have a 50 percent greater likelihood of dying.

Sitting for long periods is bad because the human body was not designed to be idle. I have worked in obesity research for several decades, and my laboratory has studied the effect of sedentary lifestyles at the molecular level all the way up to office design. Lack of movement slows metabolism, reducing the amount of food that is converted to energy and thus promoting fat accumulation, obesity, and the litany of ills—heart disease, diabetes, arthritis, and more—that come with being overweight. Sitting is bad for lean people, too. For instance, sitting in your chair after a meal leads to high blood sugar spikes, whereas getting up after you eat can cut those spikes in half.

The public usually associates these health problems with eating too much, not with sitting too much. My experience with people who struggle with their weight has led me to think that sitting habits might be just as pernicious. Still, a sedentary way of life might be easier to change than eating habits.

Peter (not his real name), a client in one of my programs in Minneapolis, told me, "I'm stuck." He was 44 years old, 50 pounds overweight and had type 2 diabetes. His doctor wanted him to start insulin injections. I sent him to my lab at the Mayo Clinic. There he watched the data as we measured his metabolic rate: strolling at less than two miles per hour increased his energy expenditure by 200 calories an hour. Afterward, Peter and I walked and talked. "Just by conducting two of your daily meetings strolling like this," I explained to him, "you'll burn 400 extra calories a day."

Peter took the advice to heart and began these easy walks. He did not diet, yet in the first year after his assessment, he lost 25 pounds. He dropped 10 more the next year. Peter never needed insulin and—as happens in many diabetics who lose weight—stopped taking diabetes medications altogether. He took this "get up" message home: he started going on bicycle rides and art gallery strolls with his family.

Peter is not alone in his success. Many studies support the view that simple movement has dramatic health effects. What is more, the effects do not require thrice-weekly visits to the gym or daily jogs that people soon abandon when the regimens become inconvenient. Nonexercise motion, done for several periods a day, can do the trick. And workers, companies and schools have already begun to institute an array of measures that encourage employees to get up out of their chairs.

MAGIC UNDERWEAR

MUCH OF THE EVIDENCE for the benefits of simple standing and walking during the day grew out of studies my group has conducted since 2001 to compare people in agricultural communities with those, like Peter, who live in industrial, urban settings. To measure sitting and moving, we took Spandex underwear and added tiny posture and motion sensors that captured body movement in 13 directions every half a second for 10 days. Jokingly, my colleagues and I call this apparel "magic underwear," but it collects a serious amount of data. We asked villagers liv-

Illustration by Scott Brundage

ing around a banana plantation in Jamaica, city dwellers in the island's capital, Kingston, and urbanites in the U.S. to wear the togs for 10 days. Among our findings: People who live in rural areas in Jamaica walk twice as much as even lean people living in Kingston and modern cities in the U.S. Those in agricultural communities sit for only three hours a day, whereas office workers can sit for 15 hours a day. Because of this increased activity, as we noted in a 2011 summary of this research in *Urban Studies,* agricultural work burns 2,000 calories more a day than many office jobs.

I was intrigued by the idea that converting sitting time to walking time could use so many calories. I called this phenomenon "nonexercise activity thermogenesis," or NEAT. NEAT is the energy a person expends going about his or her everyday life. And I wondered if it made a difference in the weight of people with similar kinds of jobs and surroundings, not just our agricultural and urban workers.

For a hint, we compared lean and obese people in the U.S. who lived in similar environments and had similar diets and jobs. We had our subjects don the magic underwear, and it revealed that obese people sit 2.25 hours longer than their lean counterparts every day. These sedentary obese people expended 350 calories fewer a day through walking and other NEAT activities than did lean people.

The pattern was suggestive but not definitive. To see if low levels of these nonexercise activities could cause weight gain, we began what came to be known as the "Great Gorging Experiment." We asked 16 lean volunteers to overeat while we monitored them carefully. Every day for eight weeks, each volunteer received 1,000 calories a day beyond their normal energy needs.

Some of our volunteers were like those frustrating friends—we all seem to have them—who do not put on weight despite continuous doughnut consumption. These volunteers gained almost no body fat after eight weeks and a total of 56,000 extra calories. How did they stay thin? Our underwear sensors showed they increased their NEAT levels, although none of them said they made a conscious effort to do so. In contrast, other overfed volunteers deposited almost every extra calorie in their body fat. The reason that these volunteers gained so much fat was that they did not change their NEAT—they remained stuck to their chairs, as we reported in *Science* in 1999.

These people were ignoring a drive to move that is as biological as breathing. In animals, movement enables aggressors to chase, the threatened to flee, the forager to search, and the reproductive to find mates. Rodent experiments show that there is intricate brain circuitry that monitors and responds to calorie expenditure, activity and rest. It is located in an area called the hypothalamus, which also regulates such functions as temperature and sleep-wake cycles.

Moreover, investigators have determined over the past decade that part of the hypothalamus manages appetite and will make you hungry if you spend a whole day raking leaves. Meanwhile a feedback system from the muscles senses muscular overexertion and signals a person to sit and rest. The modern chair-based environment has overwhelmed this biologically driven balancing act.

WHAT CAN WE DO?

WE ARE NOT, however, prisoners of this environment. We can break free. Although technologies such as computers and video games have contributed to the allure of the chair, technology can also be a part of the solution. The cell phone, for instance, enables a seated conversation to become a walking talk. A host of popular activity-sensing gadgets enable people to measure how often they sit or stand or move. Newer video games, called Exergames, link computers to physical competitions; the Nintendo Wii, which encourages movement, was a game changer here.

Work can become more active as well. On behalf of some corporations, my lab has redesigned workplaces that release employees from their chair-based isolation. One company in St. Paul, Minn., encouraged walk-and-talk meetings by taping walking tracks to its carpets. A firm in Iowa discouraged workers from sending e-mail to their colleagues nearby by creating "'e-mail-free work zones"; computer networks can block e-mail to close-by desktops.

A decade ago I came up with the idea of a treadmill desk as a way to allow office workers to do their jobs while moving. The unit allows people to walk while conducting business. A computer is placed on a high table with a slow-speed (1 to 2 mph) treadmill underneath it. A person can stroll while typing, answering e-mails and taking phone calls. Naturally, as the inventor, I think the desk is a good idea, and I was pleased when a study, published in *Health Services Management Research* in 2011, demonstrated that it could be helpful. It reported that people who use the desks are slimmer, are less stressed, and have lower blood pressure and cholesterol levels. The desk, of course, is not the only way to incorporate more activity into your day.

As is true of offices, schools can become more active places. We helped to build a classroom in Rochester, Minn., where students practiced spelling while strolling and mathematics while throwing balls. In Idaho Falls a classroom was redesigned so that all the sit-down desks were replaced with standing desks that had a "fidget bar" for students to swing their legs on. Studies show that enrollees in schools that promote movement are twice as active as those attending traditional schools. Educational test scores also improve by about 10 percent, and their hormone levels were in healthier ranges.

Cities can be reimagined to encourage movement. Analyses conducted in San Francisco and the U.K. demonstrate that city districts can be rezoned to discourage car-based travel. Commute times increase by only a handful of minutes, air quality improves, and medical expenses drop. Chair-free living does not just promote health but also saves money.

We live amid a sea of killer chairs: adjustable, swivel, recliner, wing, club, chaise longue, sofa, arm, four-legged, three-legged, wood, leather, plastic, car, plane, train, dining and bar. That's the bad news. The good news is that you do not have to use them. Pat yourself on the back if you read this article standing up—and if you didn't, get up! SA

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David Pogue is the anchor columnist for Yahoo Tech and host of several *NOVA* miniseries on PBS.

Crash Test Dummies

Whether you like it or not, you're a beta tester

I taught a class a few years ago at Columbia Business School called "What Makes a Hit a Hit—and a Flop a Flop." As a grizzled 25-year veteran of tech product reviews, I intended to bestow my hard-won wisdom on this group of young, idealistic entrepreneurs-to-be.

I shared, for example, the story of the Storm, which was the first touch-screen BlackBerry phone. BlackBerry rushed it out the door, riddled with embarrassing bugs, hoping to catch the 2008 holiday season. That was about the last most people heard of it.

"Never treat your customers as beta testers," I concluded. "Get your software right the first time. It's hard to recover from a bad first impression."

I nodded my head, satisfied that I'd made my point—when I noticed that three or four hands had shot into the air. They belonged to students who had spent their summers working at software companies.

"But software is never really finished," argued one young woman. "You ship something that's reasonably close; you can always push out a software fix later."

I was aghast. "You would ship your software knowing that there are bugs in it?"

By this point, my students were all but rolling their eyes at me. "Professor Pogue, every software product ships with known bugs. You try to fix the big ones in time for 1.0, but then you have to put it out there to get the revenue flowing. You can always polish it up later." Really, I thought?

On the train ride home, I realized they were right about one thing: buggy software isn't just an occasional fluke; it's now the rule. Tech companies routinely treat their paying customers as unpaid beta testers.

It's not just about bugs, either. These days software designers let public feedback guide the fundamental design of the software: what features it offers, how it works.

Let me be clear: I'm a huge, raving fan of crowdsourcing. The wisdom of the masses beats the wisdom of a few programmers every time. That's why beta-testing programs are such a win-win: tech fans get to try out some new product early (and shape its development), and the company gets thousands of guinea pigs scouring for flaws—for free.

That's why Microsoft offers each new version of Windows to the public months before it is finished. This year, for the first time in many years, Apple did the same with its OS X Yosemite operating system. And Google is famous for labeling its services "beta" for a very, very long time. (Google Docs was in beta testing for three years; Gmail, five years.)

But those unfinished products are *free* and *labeled* "beta." Where things get ugly is when companies sell products—without telling their audience that the software isn't fully baked.

Part of our disgruntlement at being served flawed software probably stems from our conception of software itself—as something that is, in fact, finishable. Software used to come in boxes, bearing version numbers. We understood each as a milestone—a program frozen in stone.

But nowadays software is a living, constantly evolving entity. Consider phone apps: nobody seems to mind that new versions pour out *constantly,* sometimes many times a year. Or Web sites: they're software, too, and they're perpetually changing.

Maybe that's why Adobe no longer produces boxed, numbered versions of Photoshop; instead the only way to get Photoshop is to *subscribe* to its steady evolution all year long.

Maybe it's time to stop thinking about traditional programs any differently. Maybe we should get rid of frozen, numbered editions, much as Adobe has done.

That wouldn't eliminate the frustration of bugginess, but at least we would comprehend software's true nature: a product that is never finished. SA

SCIENTIFIC AMERICAN ONLINE
The most egregious tech bugs: ScientificAmerican.com/nov2014/pogue

Illustration by Olena Shmahalo

NEUROSCIENCE

mind of the meditator

Contemplative practices that extend back thousands of years show a multitude of benefits for both body and mind

By Matthieu Ricard, Antoine Lutz and Richard J. Davidson

Illustration by Marcos Chin

Matthieu Ricard is a Buddhist monk who trained as a cellular biologist before he left France to become a student of Buddhism in the Himalayas about 40 years ago.

Antoine Lutz is a research scientist at the French National Institute of Health and Medical Research and also works at the University of Wisconsin–Madison. He has been a leader in studying the neurobiology of meditation.

Richard J. Davidson has pioneered the science of meditation as director of the Waisman Laboratory for Brain Imaging and Behavior and the Center for Investigating Healthy Minds at the University of Wisconsin–Madison.

WHEN THE SOCIETY FOR NEUROSCIENCE ASKED TENZIN GYATSO, THE 14TH DALAI LAMA (the leader of Tibetan Buddhism), to address its annual meeting in Washington, D.C., in 2005, a few hundred members among the nearly 35,000 or so attending the meeting petitioned to have the invitation rescinded. A religious leader, they felt, had no place at a scientific meeting. But this particular leader turned out to have a provocative and ultimately productive question to pose to the gathering. "What relation," he asked, "could there be between Buddhism, an ancient Indian philosophical and spiritual tradition, and modern science?"

The Dalai Lama, putting action before rhetoric, had already started trying to find answers to his own question. Back in the 1980s, he had sparked a dialogue about science and Buddhism, which led to the creation of the Mind & Life Institute, dedicated to studying contemplative science. In 2000 he brought new focus to this endeavor: he launched the subdiscipline of "contemplative neuroscience" by inviting scientists to study the brain activity of expert Buddhist meditators—defined as having more than 10,000 hours of practice.

For nearly 15 years more than 100 monastics and lay practitioners of Buddhism and a large number of beginning meditators have participated in scientific experiments at the University of Wisconsin–Madison and at least 19 other universities. The article you are reading, in fact, is the product of a collaboration between two neuroscientists and a Buddhist monk who originally trained as a cell biologist.

A comparison of the brain scans of meditators with tens of thousands of hours of practice with those of neophytes and nonmeditators has started to explain why this set of techniques for training the mind holds great potential for supplying cognitive and emotional benefits. The goals of meditation, in fact, overlap with many of the objectives of clinical psychology, psychiatry, preventive medicine and education. As suggested by the growing compendium of research, meditation may be effective in treating depression and chronic pain and in cultivating a sense of overall well-being.

The discovery of meditation's benefits coincides with recent neuroscientific findings showing that the adult brain can still be deeply transformed through experience. These studies show that when we learn how to juggle or play a musical instrument, the brain undergoes changes through a process called neuroplasticity. A brain region that controls the movement of a violinist's fingers becomes progressively larger with mastery of the instrument. A similar process appears to happen when we meditate. Nothing changes in the surrounding environment, but the meditator regulates mental states to achieve a form of inner en-

IN BRIEF

Meditation is an ancient pursuit that, in some form, is a part of nearly every world religion. In recent years its practice, derived from various branches of Buddhism, has made its way into the secular world as a means of promoting calmness and general well-being.

Three common forms of meditation—focused attention, mindfulness and compassion—are now practiced everywhere, from hospitals to schools, and have increasingly become an object of scrutiny in scientific laboratories worldwide.

Physiological changes in the brain—an altered volume of tissue in some areas—occur through meditation. Practitioners also experience beneficial psychological effects: they react faster to stimuli and are less prone to various forms of stress.

Varieties of Contemplative Experience

Advances in neuroimaging and other technologies have enabled scientists to gain insight into what happens in the brain during three major forms of Buddhist meditation—focused attention, mindfulness, and compassion and loving kindness. The diagram below offers a glimpse into the cycle of events that occurs in the practice of focused-attention meditation—and the corresponding activation of specific brain areas.

Focused Attention

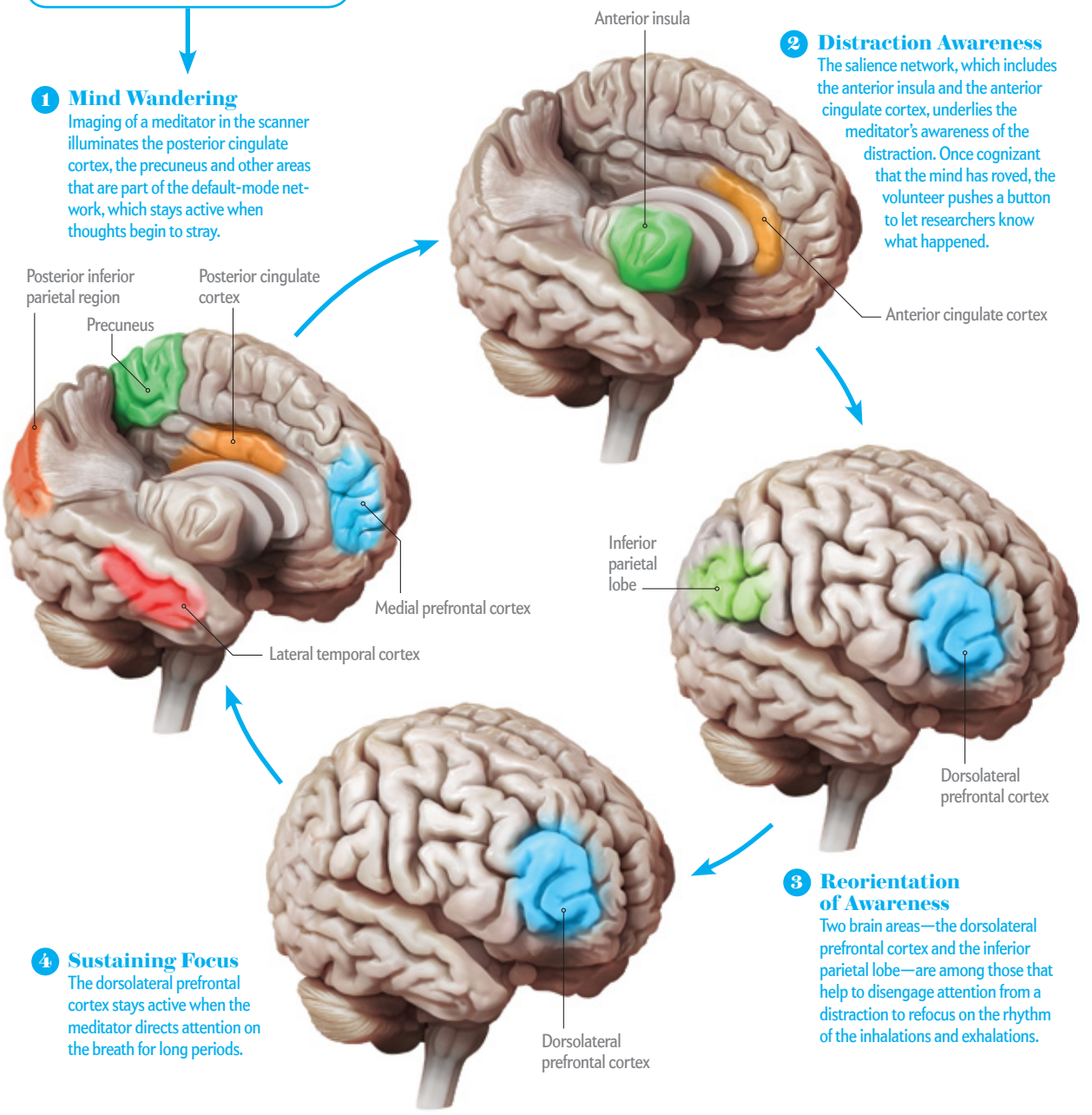
This practice typically directs the meditator to concentrate on the in-and-out cycle of breathing. Even for the expert, the mind wanders, and the object of focus must be restored. A brain-scanning study at Emory University has pinpointed distinct brain areas that become involved as attention shifts.

Mindfulness

Also called open-monitoring meditation, mindfulness entails observing sights, sounds and other sensations, including internal bodily sensations and thoughts, without being carried away by them. Expert meditators have diminished activity in anxiety-related areas, such as the insular cortex and the amygdala.

Compassion and Loving Kindness

In this practice, the meditator cultivates a feeling of benevolence directed toward other people, whether friend or enemy. Brain regions that fire up when putting oneself in the place of another—the temporoparietal junction, for instance—show an increase in activity.



1 Mind Wandering
Imaging of a meditator in the scanner illuminates the posterior cingulate cortex, the precuneus and other areas that are part of the default-mode network, which stays active when thoughts begin to stray.

2 Distraction Awareness
The salience network, which includes the anterior insula and the anterior cingulate cortex, underlies the meditator's awareness of the distraction. Once cognizant that the mind has roved, the volunteer pushes a button to let researchers know what happened.

3 Reorientation of Awareness
Two brain areas—the dorsolateral prefrontal cortex and the inferior parietal lobe—are among those that help to disengage attention from a distraction to refocus on the rhythm of the inhalations and exhalations.

4 Sustaining Focus
The dorsolateral prefrontal cortex stays active when the meditator directs attention on the breath for long periods.

Illustration by David C. Killpack

richment, an experience that affects brain functioning and its physical structure. The evidence amassed from this research has begun to show that meditation can rewire brain circuits to produce salutary effects not just on the mind and the brain but on the entire body.

WHAT IS MEDITATION?

MEDITATION HAS ROOTS in the contemplative practices of nearly every major religion. The prevalence of meditation in the media has given the word various meanings. We will refer to meditation as the cultivation of basic human qualities, such as a more stable and clear mind, emotional balance, a sense of caring mindfulness, even love and compassion—qualities that remain latent as long as one does not make an effort to develop them. It is also a process of familiarization with a more serene and flexible way of being.

In principle, meditation is relatively simple and can be done anywhere. No equipment or workout attire is needed. The meditator begins by assuming a comfortable physical posture, neither too tense nor too lax, and by wishing for self-transformation and a desire for others' well-being and for the alleviation of their suffering. Later the practitioner must stabilize the mind, which is too often disorderly—and occupied by a stream of inner chatter. Mastering the mind requires freeing it from automatic mental conditioning and inner confusion.

We will examine here what happens in the brain during three common types of meditation developed through Buddhism and now practiced in secular programs in hospitals and schools throughout the world. The first one, focused-attention meditation, aims to tame and center the mind in the present moment while developing the capacity to remain vigilant to distractions. The second one, mindfulness, or open-monitoring meditation, tries to cultivate a less emotionally reactive awareness to emotions, thoughts and sensations occurring in the present moment to prevent them from spiraling out of control and creating mental distress. In mindfulness, the meditator remains attentive, moment by moment, to any experience without focusing on anything specific. Finally, another type of practice is known in Buddhist tradition as compassion and loving kindness and fosters an altruistic perspective toward others.

UNDER THE SCANNER

NEUROSCIENTISTS HAVE NOW BEGUN to probe what happens inside the brain during the various types of meditation. Wendy Hasenkamp, then at Emory University, and her colleagues used brain imaging to identify the neural networks activated by focused-attention meditation. In the scanner, the participants trained their attention on the sensation produced by breathing. Typically during this form of meditation, the mind wanders from an object, and the meditator must recognize this and then restore attention to the gradual rhythm of the inhaling and exhaling. In this study, the meditator had to signal mind wandering by pressing a button. Researchers identified four phases of a cognitive cycle: an episode of mind wandering, a moment of becoming aware of the distraction, a phase of reorienting attention and a resumption of focused attention.

Each of the four phases involves particular brain networks. The first part of the cycle, when a distraction occurs, increases activity in the wide-ranging default-mode network (DMN). This network includes areas of the medial prefrontal cortex, the posterior cingulate cortex, the precuneus, the inferior parietal lobe and the lateral temporal cortex. The DMN is known to become activated during mind wandering and to play a general role in building and updating internal models of the world based on long-term memories about the self or others.

The second phase, becoming aware of a distraction, occurs in other brain areas such as the anterior insula and the anterior cingulate cortex, regions of what is called the salience network. This network regulates subjectively perceived feelings, which might, for instance, lead to being distracted during a task. The salience network is thought to play a key role in detecting novel events and in switching activity during meditation among assemblies of neurons that make up the brain's large-scale networks. It may shift attention away from the default-mode network, for instance.

The third phase engages additional areas—among them the dorsolateral prefrontal cortex and the lateral inferior parietal lobe—that "take back" one's attention by detaching it from any distracting stimulus. Finally, in the fourth and last phase, the dorsolateral prefrontal cortex continues to retain a high level of activity, as the meditator's attention remains directed toward an object such as the breath.

In our laboratory at Wisconsin, we further observed different patterns of activity depending on a practitioner's level of experience. Veteran meditators with more than 10,000 hours of practice showed more activity in these attention-related brain regions compared with novices. Paradoxically, the most experienced meditators demonstrated less activation than the ones without as much experience. Advanced meditators appear to acquire a level of skill that enables them to achieve a focused state of mind with less effort. These effects resemble the skill of expert musicians and athletes capable of immersing themselves in the "flow" of their performances with a minimal sense of effortful control.

To study the impact of focused-attention meditation, we also studied its volunteers before and after a three-month retreat with intensive meditation exercises for at least eight hours a day. They received headphones that broadcast sounds at a given frequency, occasionally mixed with slightly higher-pitched sounds. They had to focus on the sounds played in one ear for 10 minutes and react to periodically interspersed high-pitched tones. After the retreat, we found that meditators, compared with a nonmeditating control group, showed less trial-to-trial variation in their reaction times on this highly repetitive task, which lent itself easily to distractions. The result suggested that the meditators had an enhanced capacity to remain vigilant. The brain's electrical responses to high-pitched tones remained more stable at the second session only for the meditators.

STREAM OF CONSCIOUSNESS

THE SECOND TYPE of well-studied meditation also involves another form of attention. Mindfulness, or open-monitoring meditation, requires the meditator to take note of every sight or sound and track internal bodily sensations and inner self-talk. The person stays aware of what is happening without becoming overly preoccupied with any single perception or thought, returning to this detached focus each time the mind strays. As awareness of what is happening in one's surroundings grows,

INNER PATHWAYS of brain activity register on an electroencephalogram as co-author Matthieu Ricard meditates.

JEFF MILLER University of Wisconsin–Madison

normal daily irritants—an angry colleague at work, a worried child at home—become less disruptive, and a sense of psychological well-being develops.

With Heleen Slagter, then in our group at Wisconsin, we sought to learn about the influence of this form of training on mental functioning by measuring the participants' capacity to detect rapidly presented visual stimuli—a means to measure mindfulness meditation, which is also sometimes called nonreactive awareness. To perform this experiment, we used a task in which the participants had to detect two numbers presented on a screen rapidly, amid a succession of letters. If the second number appears about 300 milliseconds after the first one, subjects often do not see the second, a phenomenon known as attentional blink.

If the second number appears after a delay of 600 milliseconds, it can be detected without difficulty. The attentional blink reflects the limits of the brain's ability to process two stimuli presented to the observer at close intervals. When too much of the brain's attention is devoted to processing the first number, the second number cannot always be detected, although the observer usually can see it on some of the trials. We hypothesized that mindfulness training could reduce the propensity to "get stuck," or absorbed by seeing the first number. Mindfulness practice cultivates a nonreactive form of sensory awareness, which should result in a reduced attentional blink. As we predicted, after three months of an intensive retreat, the meditators perceived both numbers more frequently than the controls did. This improved perception was also reflected in lessened activity of a particular brain wave in response to the first number. Monitoring the P3b brain wave, used to assess how attention is allocated, indicated that meditators were capable of optimizing attention so as to minimize the attentional blink.

Staying aware of an unpleasant sensation can reduce maladaptive emotional responses and help one to move beyond the disagreeable feeling and may be particularly useful in dealing with pain. In our Wisconsin lab, we have studied experienced practitioners while they performed an advanced form of mindfulness meditation called open presence. In open presence, sometimes called pure awareness, the mind is calm and relaxed, not focused on anything in particular yet vividly clear, free from excitation or dullness. The meditator observes and is open to experience without making any attempt to interpret, change, reject or ignore painful sensation. We found that the intensity of the pain was not reduced in meditators, but it bothered them less than it did members of a control group.

Compared with novices, expert meditators' brain activity diminished in anxiety-related regions—the insular cortex and the amygdala—in the period preceding the painful stimulus. The meditators' brain response in pain-related regions became accustomed to the stimulus more quickly than that of novices after repeated exposures to it. Other tests in our lab have shown that meditation training increases one's ability to better control and buffer basic physiological responses—inflammation or levels of a stress hormone—to a socially stressful task such as giving a public speech or doing mental arithmetic in front of a harsh jury.

Several studies have documented the benefits of mindfulness on symptoms of anxiety and depression and its ability to improve sleep patterns. By deliberately monitoring and observing their thoughts and emotions when they feel sad or worried, depressed patients can use meditation to manage negative thoughts and feelings as they arise spontaneously and so lessen rumination. Clinical psychologists John Teasdale, then at the University of Cambridge, and Zindel Segal of the University of Toronto showed in 2000 that for patients who had previously suffered at least three episodes of depression, six months of mindfulness practice, along with cognitive therapy, reduced the risk of relapse by nearly 40 percent in the year following the onset of a severe depression. More recently, Segal demonstrated that the intervention is superior to a placebo and has a protective effect against relapse comparable to standard maintenance antidepressant therapy.

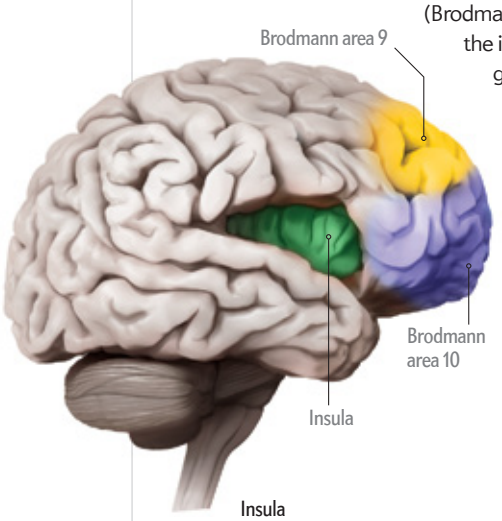
COMPASSION AND LOVING KINDNESS

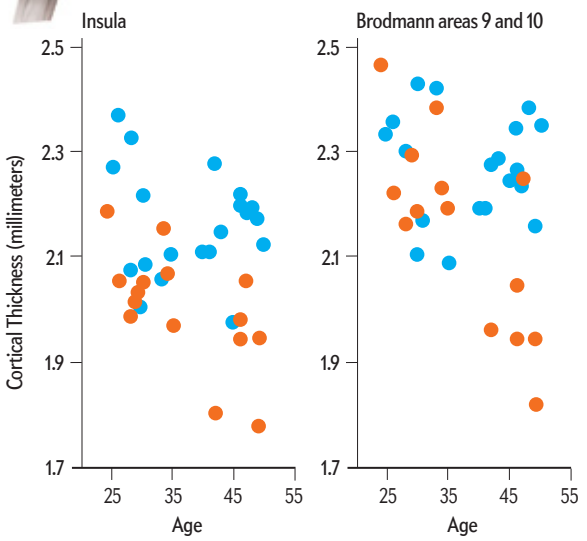
THE THIRD FORM of meditation under study cultivates attitudes and feelings of loving kindness and compassion toward other people, whether they are close relatives, strangers or enemies. This practice entails being aware of someone else's needs and then experiencing a sincere, compassionate desire to help that

A MEDITATION BENEFIT

Grow More Brain

Researchers from several universities explored whether meditation might bring about structural changes in brain tissue. Using magnetic resonance imaging, they found that 20 experienced practitioners of one type of Buddhist meditation had a greater volume of brain tissue in the prefrontal cortex (Brodmann areas 9 and 10) and the insula than a control group did (*graphs*). These regions play a role in processing attention, sensory information and internal bodily sensations. Future long-term studies will be needed to confirm this finding.





person or to alleviate the suffering of other people by shielding them from their own destructive behavior.

To generate a compassionate state may sometimes entail the meditator feeling what another person is feeling. But having one's emotions resonate empathetically with the feelings of another person does not by itself suffice to yield a compassionate mind-set. The meditation must also be driven by an unselfish desire to help someone who is suffering. This form of meditation on love and compassion has proved to be more than just a spiritual exercise. It has shown potential to benefit health care workers, teachers and others who run the risk of emotional burnout linked to the distress experienced from a deeply empathetic reaction to another person's plight.

The meditator begins by focusing on an unconditional feeling of benevolence and love for others, accompanied by silent repetition of a phrase conveying intent, such as "May all beings find happiness and the causes of happiness and be free from suffering and the causes of suffering." In 2008 we studied experienced volunteers who had practiced this form of training for thousands of hours and found an increase in activity in several brain regions while they listened to voices conveying distress. The secondary somatosensory and insular cortices, known to participate in empathetic and other emotional responses, were more activated for experts than controls in response to the distressed voice, suggesting an enhanced ability to share the feelings of others without reporting any sign of becoming emotionally overwhelmed. The practice of compassion meditation also produced more activity in areas such as the temporoparietal junction, the medial prefrontal cortex and the superior temporal sulcus, all typically activated when we put ourselves in the place of another.

More recently, Tania Singer and Olga Klimecki, both at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany, in collaboration with one of us (Ricard), sought to distinguish differences between the effects of empathy and compassion on meditators. They noted that compassion and altruistic love were associated with positive emotions, and they suggested that emotional exhaustion or burnout was, in fact, a kind of empathy "fatigue."

According to the Buddhist contemplative tradition from which this practice is derived, compassion, far from leading to distress and discouragement, reinforces an inner balance, strength of mind, and a courageous determination to help those who suffer. If a child is hospitalized, the presence of a loving mother at his side holding his hand and comforting him with tender words will no doubt do that child more good than the anxiety of a mother overwhelmed with empathetic distress who, unable to bear the sight of her sick child, paces back and forth in the hallway. In the latter case, the mother may then end up with the common experience of burnout, which, in one U.S. study, beset about 60 percent of the 600 caregivers surveyed.

To further explore the mechanisms of empathy and compassion, Klimecki and Singer divided about 60 volunteers into two groups. One meditated on love and compassion, and the other experimental regimen trained participants to cultivate feelings of empathy for others. Preliminary results showed that after a week of meditation-based loving kindness and compassion, novice subjects watched video clips showing suffering people with more positive and benevolent feelings. The other subjects, who devoted a week to an experimental regimen that just cultivated empathy, experienced emotions that resonated deeply with others' sufferings. But these emotions also brought about negative feelings and thoughts, and this group experienced more distress, sometimes to the point of not being able to control their emotions.

Aware of these destabilizing effects, Singer and Klimecki added training for the empathy group in compassion and loving kindness meditation. They then observed that this additional exercise counterbalanced the detrimental effects of training in empathy alone: negative emotions diminished, and positive emotions increased. These results were accompanied by corresponding changes in the areas of several brain networks associated with compassion, positive emotions and maternal love, including the orbitofrontal cortex, the ventral striatum and the anterior cingulate cortex. The researchers, moreover, were able

SOURCE: "MEDITATION EXPERIENCE IS ASSOCIATED WITH INCREASED CORTICAL THICKNESS," BY SARA W. LAZAR ET AL., IN *NEUROREPORT*, VOL. 16, NO. 17; NOVEMBER 28, 2005

SCIENTIFIC AMERICAN ONLINE Watch talks by Davidson and Ricard at ScientificAmerican.com/nov2014/meditation

Illustration by David C. Killpack (brain)

to demonstrate that a week of training in compassion increased prosocial behavior in a virtual game specially developed to measure the capacity to help others.

A DOOR TO CONSCIOUSNESS

MEDITATION EXPLORES the nature of the mind, providing a way to study consciousness and subjective mental states from the first-person perspective of the meditator. In a collaboration with expert Buddhist meditators at Wisconsin, we have studied the brain's electrical activity using electroencephalography (EEG) during compassion meditation in which the meditators described the well-defined sense of self as becoming less fixed and permanent.

We found that these long-term Buddhist practitioners were able, at will, to sustain a particular EEG pattern. Specifically, it is called high-amplitude gamma-band oscillations and phase synchrony at between 25 and 42 hertz. The coordination of brain oscillations may play a potentially crucial role in the brain's building of temporary networks that can integrate cognitive and affective functions during learning and conscious perception, a process that can bring about lasting changes in brain circuitry.

High-amplitude oscillations persisted throughout the meditation for several dozens of seconds and gradually increased as practice progressed. These EEG traces differed from those of control subjects, in particular, in the lateral frontoparietal cortex. Changes in electrical activity may reflect an increased awareness in expert meditators of their surroundings and their internal mental processes, although additional research is needed to better understand the functioning of gamma oscillations.

Meditation brings about changes not just in well-defined cognitive and emotional processes but also in the volume of certain brain areas, possibly reflecting alterations in the number of connections among brain cells. A preliminary study by Sara W. Lazar of Harvard University and her colleagues showed that among longtime meditators, as compared with a control group, the volume of the brain's darker tissue, its gray matter, differed in the insula and prefrontal cortices—specifically, regions called Brodmann areas 9 and 10, which are frequently activated during various forms of meditation. These distinctions were most pronounced in older participants in the study, suggesting that meditation might influence the thinning of brain tissue that comes with aging.

In a follow-up study, Lazar and her colleagues also showed that mindfulness training decreased the volume of the amygdala, a region involved in fear processing, for those participants who showed the most noticeable reductions in stress over the course of training. Eileen Luders of the University of California, Los Angeles, and her colleagues further observed differences in meditators in the fibers called axons that connect different brain regions, suggesting an enhanced number of brain connections. This observation may support the hypothesis that meditation actually induces structural alterations in the brain. An important limitation of this research relates to the lack of long-term longitudinal studies that follow a group over the course of many years and to the absence of comparisons between meditators and people of similar backgrounds and ages who do not meditate.

Some evidence even exists that meditation—and its ability to enhance overall well-being—may diminish inflammation and other biological stresses that occur at the molecular level. A collaborative study between our group and one led by Perla Kaliman of the Institute of Biomedical Research of Barcelona showed that one day of intensive mindfulness practice in experienced meditators turned down the activity of inflammation-related genes and altered the functioning of enzymes involved with turning genes on and off. A study by Cliff Saron of the University of California, Davis, looked at the effect of meditation on a molecule involved with regulating the longevity of a cell. The molecule in question was an enzyme called telomerase that lengthens DNA segments at the ends of chromosomes. The segments, called telomeres, ensure stability of the genetic material during cell division. They shorten every time a cell divides, and when their length decreases below a critical threshold, the cell stops dividing and gradually enters a state of senescence. Compared with a control group, the meditators who showed the most pronounced reductions in psychological stress also had higher telomerase activity by the end of the retreat. This finding suggests that mindfulness training might slow processes of cellular aging among some practitioners.

A PATH TO WELL-BEING

ABOUT 15 YEARS OF RESEARCH have done more than show that meditation produces significant changes in both the function and structure of the brains of experienced practitioners. These studies are now starting to demonstrate that contemplative practices may have a substantive impact on biological processes critical for physical health.

More studies using well-defined, randomized controlled trials are needed to isolate meditation-related effects from other psychological factors that can influence the outcome of a study. Other variables that may affect study results are the level of motivation of a practitioner and the roles played by both teachers and students in a meditation group. Further work is needed to understand the possible negative side effects of meditation, the desirable length of a given practice session and the way to tailor it to a person's specific needs.

Even with the requisite cautions, research on meditation provides new insights into methods of mental training that have the potential to enhance human health and well-being. Equally important, the ability to cultivate compassion and other positive human qualities lays the foundation for an ethical framework unattached to any philosophy or religion, which could have a profoundly beneficial effect on all aspects of human societies. SA

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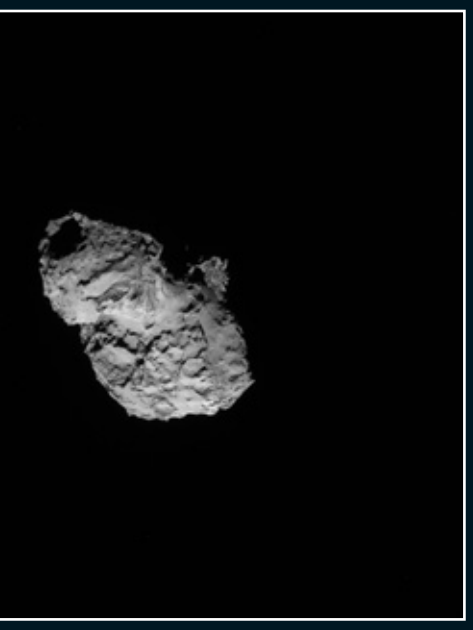
ZOOMING IN: **As the Rosetta spacecraft approached Comet 67P/Churyumov-Gerasimenko, it captured these increasingly detailed views.**



SPACE

Pluto and Beyond

For the first time, spacecraft will get an up-close look at comets, asteroids and dwarf planets from the distant Kuiper belt. These probes should reveal how the solar system came to be

By Michael D. Lemonick

Michael D. Lemonick is a writer at Climate Central, a nonprofit news site, and author of *Mirror Earth: The Search for Our Planet's Twin* (Walker Books, 2012). For 21 years he was a science writer for *Time* magazine.

JANUARY 20, 2014, WAS GOING TO BE EITHER A VERY good or a very bad day for the men and women working on the Rosetta space probe. The 3,000-kilogram robotic spacecraft had been launched by the European Space Agency nearly 10 years earlier and was en route to an August encounter with an obscure comet bearing the unwieldy name 67P/Churyumov-Gerasimenko (67P for short). If all went according to plan, Rosetta would do something that has never been attempted before: it would loop into a tight orbit around the comet, deploy a lander named Philae to touch down on its surface, and shadow the frozen body as it crackled to life, warmed by the heat of the sun.

But for any of that to happen, Rosetta first had to wake up. It had been placed into an energy-conserving state of hibernation more than two years before. At 11 A.M. Central European time on January 20, its internal alarm clock was set to go off. The scientists and engineers waiting in a control room at the European Space Operations Center in Darmstadt, Germany, were confident that the craft would report in as planned. But they were also mindful of the Mars Observer probe, which, in 1993, vanished from radio contact without a trace. For a few minutes, it seemed as though it might be happening again.

"I saw a lot of white faces around the room," recalls Holger Sierks of the Max Planck Institute for Solar System Research in Göttingen, Germany, who is in charge of the spacecraft's optical and infrared cameras. It felt like an eternity, although it was more like 15 minutes—but finally, an electronic ping reached Darmstadt from out beyond Jupiter. "It said, 'Here I am again,'" Sierks says, "and that was an enormous relief."

In the ensuing weeks it became clear that Rosetta was not just awake but fully functional and poised to answer crucial questions about the structure, composition, behavior and origin of comets—icy bodies that have remained largely unaltered since the solar system formed some 4.6 billion years ago. Later this month Rosetta will release its lander, which will drill down past the comet's surface to excavate the very history of the solar system.

Rosetta is not alone out there, either. In July 2015, after its own nine-year journey, NASA's New Horizons probe will perform another first: a close flyby of Pluto and its five known moons. "The spacecraft is in spectacularly good shape," reports principal investigator Alan Stern of the Southwest Research Institute's office in Boulder, Colo. And although the two missions are independent, they are not unrelated. Astronomers now understand that Pluto and 67P are members of the Kuiper belt, a vast, largely uncharted swarm of billions of objects beyond Neptune, ranging in size from a few meters to more than 2,000 kilometers across.

These encounters will cap off a series of discoveries over the past two decades that have, as Stern puts it, "blown the doors off and literally rewritten everything we thought we knew about the architecture of the solar system." Just a bit more than 20 years ago, in fact, nobody even knew that the Kuiper belt existed. Since then, planetary scientists have discovered a handful of frozen worlds that approach and even rival Pluto in size. They have seen

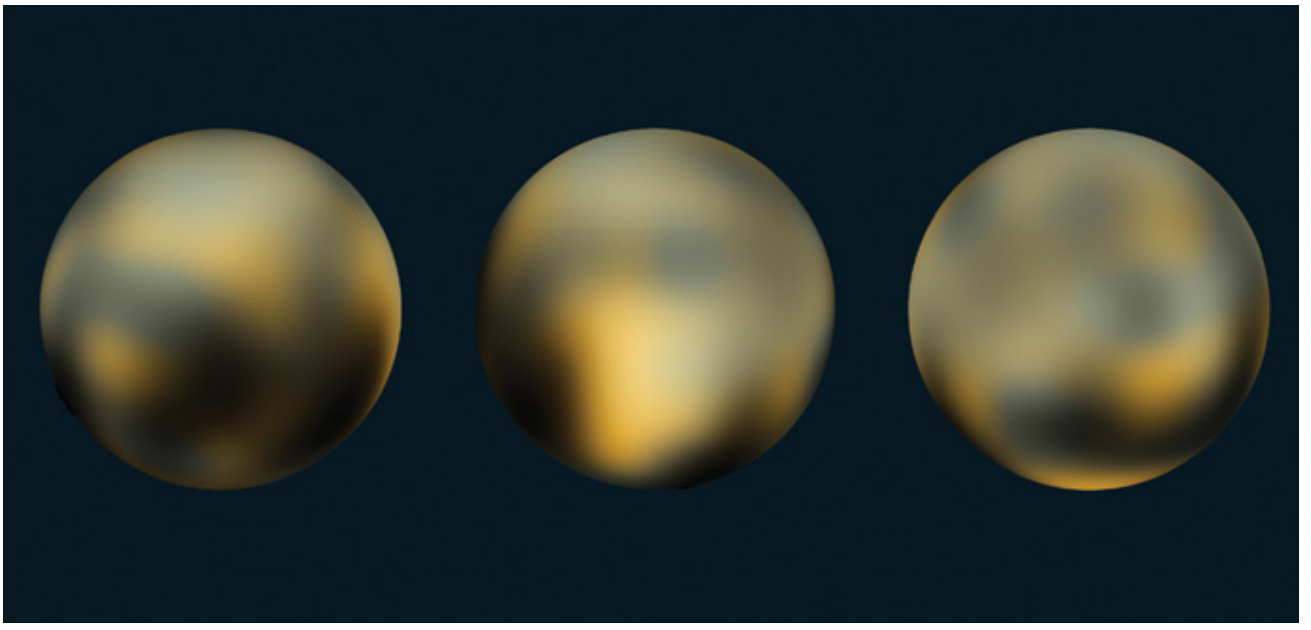
IN BRIEF

The Kuiper belt is a band of billions of icy asteroids beyond Neptune that are nearly pristine examples of the solar system's ingredients.

Two spacecraft are on missions to probe the belt's secrets. One, called Rosetta, is orbiting a comet that was born in the Kuiper belt. The other, New Horizons, is en route to Pluto, the region's largest resident.

By studying the makeup of the Kuiper belt, these missions could hold the key to the solar system's origins.

PRECEDING PAGES: COURTESY OF ESA, ROSETTA AND NAVCAM



FUZZY VIEW: **The surface terrain of Pluto, as seen by the Hubble Space Telescope, varies widely, with a mysterious bright spot appearing in the center view. The New Horizons probe should image Pluto with much more clarity when it arrives next year.**

COURTESY OF NASA, ESA AND M. BUIE *Southwest Research Institute*

evidence that points to a long-ago violent reshuffling of the orbits of Jupiter, Saturn, Uranus and Neptune—and maybe even to the existence of a lost fifth giant planet. They have analyzed the sizes and orbits of the 1,500 or so known Kuiper belt objects (KBOs) to get a handle on how the belt itself took shape—wondering whether crashing icefalls from the nascent Kuiper belt once bestowed oceans on a young, dry Earth.

Each of these observations has served as a narrow window into the origin and evolution of the Kuiper belt. Together, however, like the apocryphal story of the blind men and the elephant, they have begun to paint a more comprehensive picture of its structure, composition and evolution. And with two spacecraft nearing first-ever close encounters with two very different KBOs, that picture is about to become dramatically clearer.

DISCOVERED AGAIN

WHEN A YOUNG ASTRONOMER named Clyde Tombaugh spotted a new body out beyond Neptune in 1930, he and the rest of the astronomical community had no doubt that he had found "Planet X," the long-suspected ninth planet in the solar system. Initially the new object—named Pluto at the suggestion of an 11-year-old British schoolgirl named Venetia Burney—was calculated to have a mass similar to Earth's. By the 1970s, however, it was clear that Pluto was smaller and much less massive than Earth's moon. What Tombaugh had actually found was the brightest member of the Kuiper belt.

Nobody would realize until the 1980s, however, that such a thing as the Kuiper belt even existed. That included Gerard Kuiper, the Dutch-American astronomer whose name it bears. In the 1950s Kuiper proposed that the region just beyond Neptune might once have been filled with icy bodies. But he thought that the gravity of "massive" Pluto would have scattered them away into deep space. That part of the solar system, he wrote, should be mostly empty. "It was really an antiprediction," says University of California, Los Angeles, astronomer David C. Jewitt, a pioneer in observations of the outer solar system.

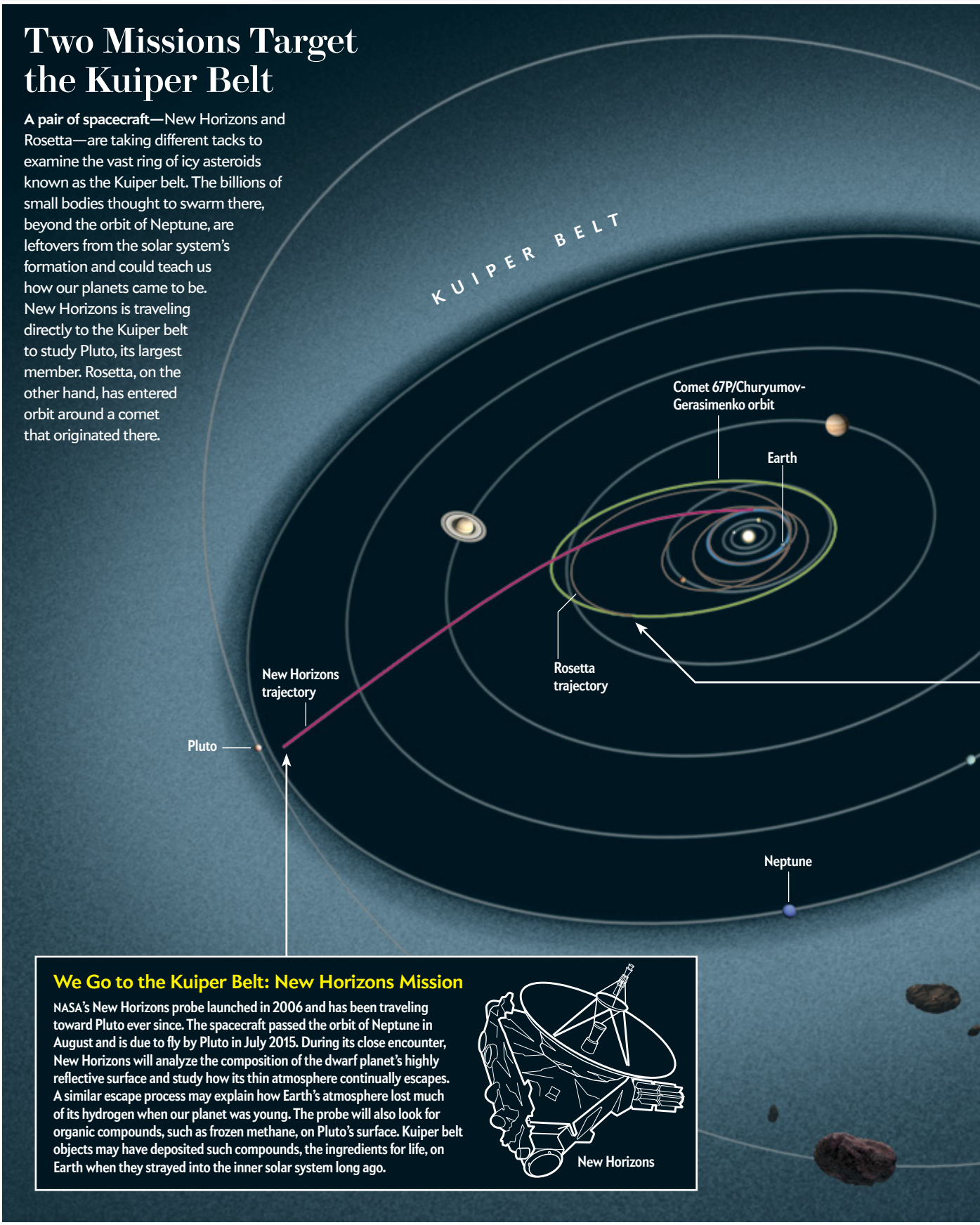
At about the same time, Kuiper's countryman Jan Oort hypothesized that those widely scattered objects would have formed a spherical cloud of proto-comets orbiting as much as a light-year away from the sun. Occasionally, he suggested, one of them would be jostled loose and fall into the inner solar system, where it would burst into life as a comet. This scenario neatly explained the existence of long-period comets, which fall in from all directions and whose orbital paths take at least 200 years to complete.

But it did not explain shorter-period comets, which tend to zoom in along the relatively flat plane where the planets dwell. Oort thought these were just long-period comets that had been diverted into shorter orbits by close encounters with the giant planets, and nobody had a better idea. (Or almost nobody: back in the 1940s, Irish astronomer Kenneth Edgeworth had suggested the short-period comets came from a swarm of small bodies whose home was much closer in. But he made the suggestion in a general way and only in passing. "If you think that counts as a prediction, fine," says Michael E. Brown, the California Institute of Technology astronomer whose 2005 discovery of the Pluto-size KBO Eris ended up demoting Pluto to the status of "dwarf planet" the following year. Brown clearly does not think it counts, and in any case, nobody paid any attention to Edgeworth's idea at the time.)

The first legitimate prediction of the Kuiper belt's existence, most planetary scientists now agree, came from Uruguayan astronomer Julio Fernández. His 1980 paper "On the Existence of a Comet Belt beyond Neptune" made the same case Edgeworth

Two Missions Target the Kuiper Belt

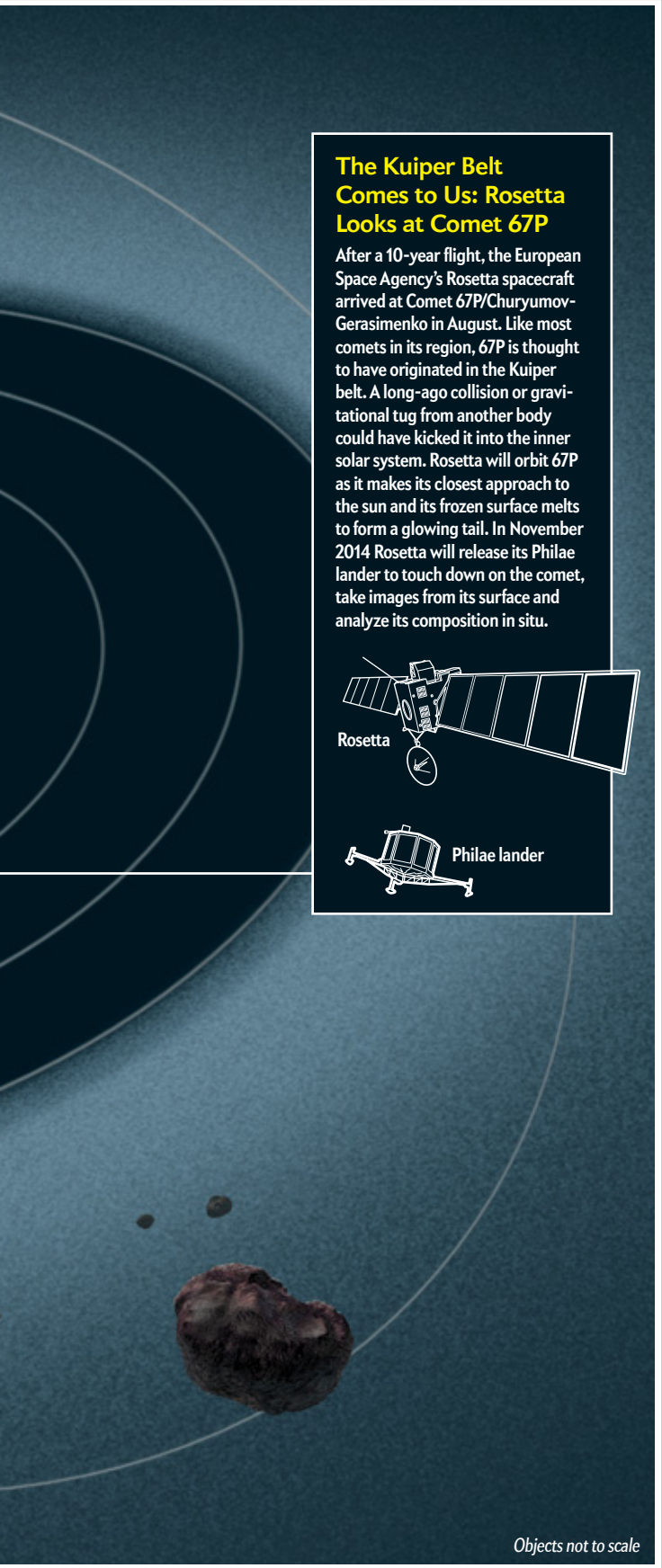
A pair of spacecraft—New Horizons and Rosetta—are taking different tacks to examine the vast ring of icy asteroids known as the Kuiper belt. The billions of small bodies thought to swarm there, beyond the orbit of Neptune, are leftovers from the solar system's formation and could teach us how our planets came to be. New Horizons is traveling directly to the Kuiper belt to study Pluto, its largest member. Rosetta, on the other hand, has entered orbit around a comet that originated there.



We Go to the Kuiper Belt: New Horizons Mission

NASA's New Horizons probe launched in 2006 and has been traveling toward Pluto ever since. The spacecraft passed the orbit of Neptune in August and is due to fly by Pluto in July 2015. During its close encounter, New Horizons will analyze the composition of the dwarf planet's highly reflective surface and study how its thin atmosphere continually escapes. A similar escape process may explain how Earth's atmosphere lost much of its hydrogen when our planet was young. The probe will also look for organic compounds, such as frozen methane, on Pluto's surface. Kuiper belt objects may have deposited such compounds, the ingredients for life, on Earth when they strayed into the inner solar system long ago.

Illustrations by Don Dixon (solar system) and George Retseck (spacecraft)



had but with far more scrupulous detail. In 1988 Scott Tremaine, then at the University of Toronto, along with his colleagues Martin Duncan and Thomas Quinn, showed that the swarm of bodies Fernández had predicted would in fact explain the frequency and trajectories of short-period comets. They were the first to use the term "Kuiper belt," although, says Tremaine, now at the Institute for Advanced Study in Princeton, N.J., "it's probably the wrong term. Fernández is really the one we should have named it for."

While Tremaine, Duncan and Quinn were nailing down the theoretical case for the Kuiper belt, Jewitt and Jane X. Luu, then his student at the Massachusetts Institute of Technology, began looking for hard evidence. Their search was not motivated by the predictions: Jewitt and Luu did not know about Fernández's paper, and they began their search in 1986, two years before Tremaine and his colleagues published their results. "What encouraged us and motivated us," Jewitt says, "was this simple idea that it's just weird that the outer solar system would be so empty."

Of course, it was not empty. In August 1992, using a 2.2-meter telescope at the summit of the extinct volcano Mauna Kea in Hawaii, Jewitt and Luu found the first KBO, 1992 QB1, as part of what they called the Slow Moving Object survey. They found the second KBO about six months later, and while Jewitt and Luu were pretty much the only ones searching at the time, "the astronomical community wised up quickly," Jewitt says. Astronomers have now identified about 1,500 KBOs; based on these numbers, they estimate that the Kuiper belt is home to 100,000 objects more than 100 kilometers across and up to 10 billion larger than two kilometers across. "For every asteroid in the main asteroid belt," Jewitt says, "there are 1,000 objects in the Kuiper belt. It's staggering to me."

Many astronomers, however, are more shocked by what *isn't* in the Kuiper belt. According to their best models of planet formation, it should boast objects as big as Earth and even bigger. Yet while Pluto has been joined by objects that rival it in size—worlds such as Makemake, Haumea, Quaoar and Eris—nothing has yet been found that comes close to any of the planets. "There's a vast number of bodies out there," Jewitt says, "but all told, they only add up to a 10th of the mass of Earth. That's really kind of puny."

Something must have happened early in the solar system's history to snuff out the largest members of the Kuiper belt. For years planetary astronomers have argued about what it could be. With Rosetta and New Horizons, they should finally start getting some answers.

EJECTION MODEL

BY THE TIME the Kuiper belt was discovered, physicists had already established how the solar system came to be. It began with a huge interstellar cloud of gas and dust, which collapsed to form a spinning disk. At its core, gravity pulled the disk into a knot of matter so dense and hot that it burst into thermonuclear fire, thus forming the sun.

The sun's heat and radiation drove most of the gases and some of the dust outward; closer in, the dust congealed into pebbles, then boulders, then asteroid-size bodies known as planetesimals. Finally, in the last states of planet formation, hundreds of Mars-size objects would have been flying around, smashing apart, slamming together again and ultimately forming the eight planets we see today—not just the rocky inner

planets but also Jupiter, Saturn, Uranus and Neptune, which are basically chunks of rock with enough gravity to vacuum up enormous amounts of surrounding gas.

Beyond Neptune, the "dust" would have been mostly ice particles, which should have formed into planet-size objects by a similar process. There are two problems with this scenario. One is that astronomers simply do not see these planet-size objects (although, Brown says, for all we know, there might be a few objects as big as Mars out in the distant Oort cloud, where they cannot be detected with current technology).

The solar system might have once boasted a fifth gas-giant planet, which would have been ejected into interstellar space.

The other problem is that there is not enough matter in the Kuiper belt to account for the existence of any objects of *any* size. If all of the material in all existing KBOs had started out as a primordial cloud of icy dust, that cloud would have been too widely dispersed to ever form into anything at all.

The very existence of the Kuiper belt therefore appears inconsistent with how theorists believe it must have formed. "The consensus solution," Jewitt says, "is that in the beginning there was far more material—30, 40 or even 50 Earth masses' worth" in the Kuiper belt. This material did form into a gigantic swarm of objects, but that collection was whittled down somehow.

The most plausible mechanism for the "somehow," first suggested by Renu Malhotra, a physicist at the University of Arizona, is that the solar system's four giant planets—Jupiter, Saturn, Uranus and Neptune—were once crowded much more closely together than they are now.

Malhotra and several of her colleagues argued that gravitational interactions between these tightly bunched planets and the primordial gaggle of KBOs pushed Saturn, Uranus and Neptune outward. At the same time, Jupiter, interacting with both KBOs and asteroids, moved inward.

These gravitational encounters would not only have shuffled the planets around but would also have flung many KBOs out to the far edges of the sun's gravitational influence, creating the distant Oort cloud, and have thrown many asteroids in toward the inner solar system. During their migration, moreover, Jupiter and Saturn would have found themselves, for a time, in a resonance with each other, a situation in which Saturn would have made exactly one orbit for every two of Jupiter's.

With the extra gravitational punch generated by having two planets lined up so precisely, KBOs would have been scattered with such vigor that more than 99 percent of them would have been swept away. Some would have ended up in the Oort cloud. Others would have smashed into the inner planets in a cataclysm known as the late heavy bombardment. "The solar system would have taken a savage beating," Jewitt says.

At least one physicist, David Nesvorný of the Southwest Research Institute, takes the idea one step further. The solar system might, he argues, have once boasted a fifth gas-giant planet, which would have been ejected into interstellar space during this violent reshuffling.

If the reshuffling of the giant planets really happened, it could explain why the Kuiper belt has no truly large objects: the material that would have built them was prematurely swept away. The objects that did form, moreover, would have looked a lot like planetesimals—small proto-planets that later combined to form planets. In this view, the Kuiper belt is like a snapshot, frozen in time, of what the rocky inner solar system looked like just a few million years after the planet-formation process had gotten under way.

"The biggest uncertainty in how the existing planets formed," says M.I.T. planetary scientist Hilke Schlichting, "is the formation of the planetesimals—how they came to exist and how big they were." That information is long gone from the inner solar system, but using a combination of observations and models, she and her colleagues have shown that the size distribution of Kuiper belt objects can be explained if the icy planetesimals they came from were typically about a kilometer across—an insight that might apply to the inner planets as well. "We're beginning to learn," she says, "after decades of speculation, about the initial conditions for planet formation."

PLUTO'S CLOSE-UP

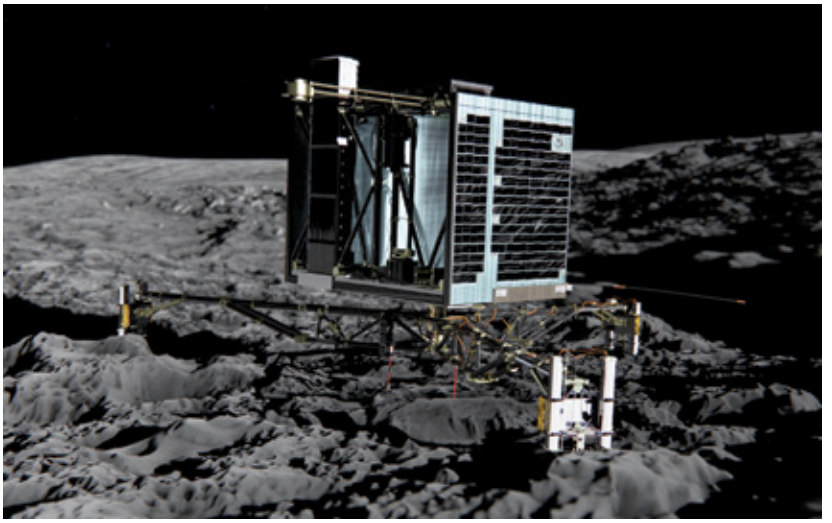
MODELS AND REMOTE OBSERVATIONS have told planetary scientists an enormous amount about the structure and likely history of the Kuiper belt. That is no substitute for close-up observations, however, as scores of space probes to all the planets and dozens of moons and asteroids have shown. "A Hubble picture of Pluto is cool," Stern says, "but it's just a couple of pixels across." By next June, "Pluto will come rushing up to us as a real world," he adds.

That world was still a planet when New Horizons launched in January 2006; its demotion to dwarf planet did not come until the next summer. But whatever you call it, Stern and his co-investigators will try to learn as much as they can as the craft speeds toward and past Pluto and its moon Charon at nearly 40,000 kilometers an hour, coming within just 10,000 kilometers of its frozen surface.

One goal will be to count the craters that are virtually certain to pockmark Pluto's icy surface, noting not just their overall number but also how many there are of a given size. That information will provide astronomers with an independent measure of the sizes of KBOs themselves, which would have smashed into Pluto in proportion to their abundance in the belt.

"But it's even better than that," Stern says. Over time, Pluto's craters get scoured away by the same processes that create its wispy atmosphere: the repeated heating and cooling of its surface as the dwarf planet moves through its elongated orbit. Charon, however, has no atmosphere, which means that all its

SCIENTIFIC AMERICAN ONLINE See video animations of Rosetta's and New Horizons's journeys at ScientificAmerican.com/nov2014/kuiper-belt



LANDING GEAR: Rosetta's Philae lander will descend to the surface of Comet 67P and attach itself with a harpoon and ice screws. There it will drill into the comet to extract samples and analyze their composition in its onboard laboratory.

impacts have been preserved. "You can compare those two," Stern says, "and find out how the impact history has changed, what the size range of projectiles is today versus what it was in the ancient Kuiper belt."

New Horizons will also seek signs of a subsurface ocean. Planetary scientists have already found oceans tucked under the thick icy shells of some of the moons of Jupiter and Saturn: Europa, Ganymede, Enceladus and Titan. If Pluto has ice geysers or volcanoes, that is a clue that the interior is warm and watery—perhaps as the result of radioactive decay in a rocky core. And even if there are not outward signs of heat, the probe's infrared cameras can detect warm spots on the surface. The idea that life could exist inside Pluto is utterly speculative—but because liquid water is considered a necessary ingredient for biology as we know it, its discovery would at least make such speculation legitimate.

The spacecraft will do all this and more in just five months, with the most intense study coming in the day or so it takes to whiz past the dwarf planet. But it will take some 16 months for the data to be relayed, bit by bit, over the nearly five billion kilometers back to Earth.

DANCE WITH A COMET

ROSETTA WILL SPEND almost that long orbiting just above the surface of 67P. In contrast to New Horizons, which will zip past Pluto at high speed, Rosetta will fly in formation with its target for 15 months, enabling it to answer all kinds of questions about 67P's precise chemical makeup and its internal structure—valuable clues to understanding the nature of the gas and dust that originally built the Kuiper belt and the way KBOs were assembled. Scientists' current understanding is so rudimentary at this point that there is no "smoking gun" that could plausibly vindicate one theory and destroy the competition. What Rosetta finds, however, could help researchers put together a convincing theory for the first time.

The journey will also give Rosetta and its lander Philae a front-row seat as the comet awakens as it comes closer to the sun. "We'll be alongside the comet right through the summer of 2015, when activity is at a maximum and the nucleus is expelling 1,000 kilograms of material per minute," says Matt Taylor of the European Space Agency, who is the principal investigator for the mission as a whole. Researchers still do not know if this material will come from all over the comet's surface or whether it will spray from small hotspots. A year from now that question will be answered, helping planetary scientists understand how and why comets eventually lose their ices and burn out.

Rosetta should also be able to address questions about us. In particular, where did Earth's water come from? Many planetary scientists believe that a storm of comets early in the solar system's history first delivered water to Earth. Rosetta will test this hypothesis by measuring whether the H_2O locked up in 67P's ice is chemically identical to the H_2O on Earth. There is already evidence from the Herschel Space Observatory that at least some comets carry water with the same ratio of hydrogen to its heavier isotope, deuterium, as the water in Earth's oceans. But Rosetta's instruments will get a far closer and more leisurely look at the comet's water and other constituents, including carbon-rich organic compounds that may have played a role in the origin of life.

Philae and Rosetta will also work together to settle the question of whether comets are simply large chunks of dirty ice or groups of smaller chunks that stick together relatively loosely under their own gravity. When the Rosetta orbiter is on the opposite side of the comet from Philae, it will beam a radio signal down through the body of the comet to Philae, where it will be reflected back. It is analogous to a CT scan, and it will show the scientists the inner structure of a comet for the first time.

Unfortunately for most of us, 67P will never be visible to the naked eye. Just as with Pluto and the vast majority of KBOs, you need artificial magnification even to know the comet is there. It is therefore no wonder that astronomers have only recently come to understand that the Kuiper belt exists at all and to appreciate its potentially crucial role in the history and architecture of the solar system.

By the end of next year, thanks to two probes that set out on their journeys nearly a decade ago, we will understand incomparably more. SA

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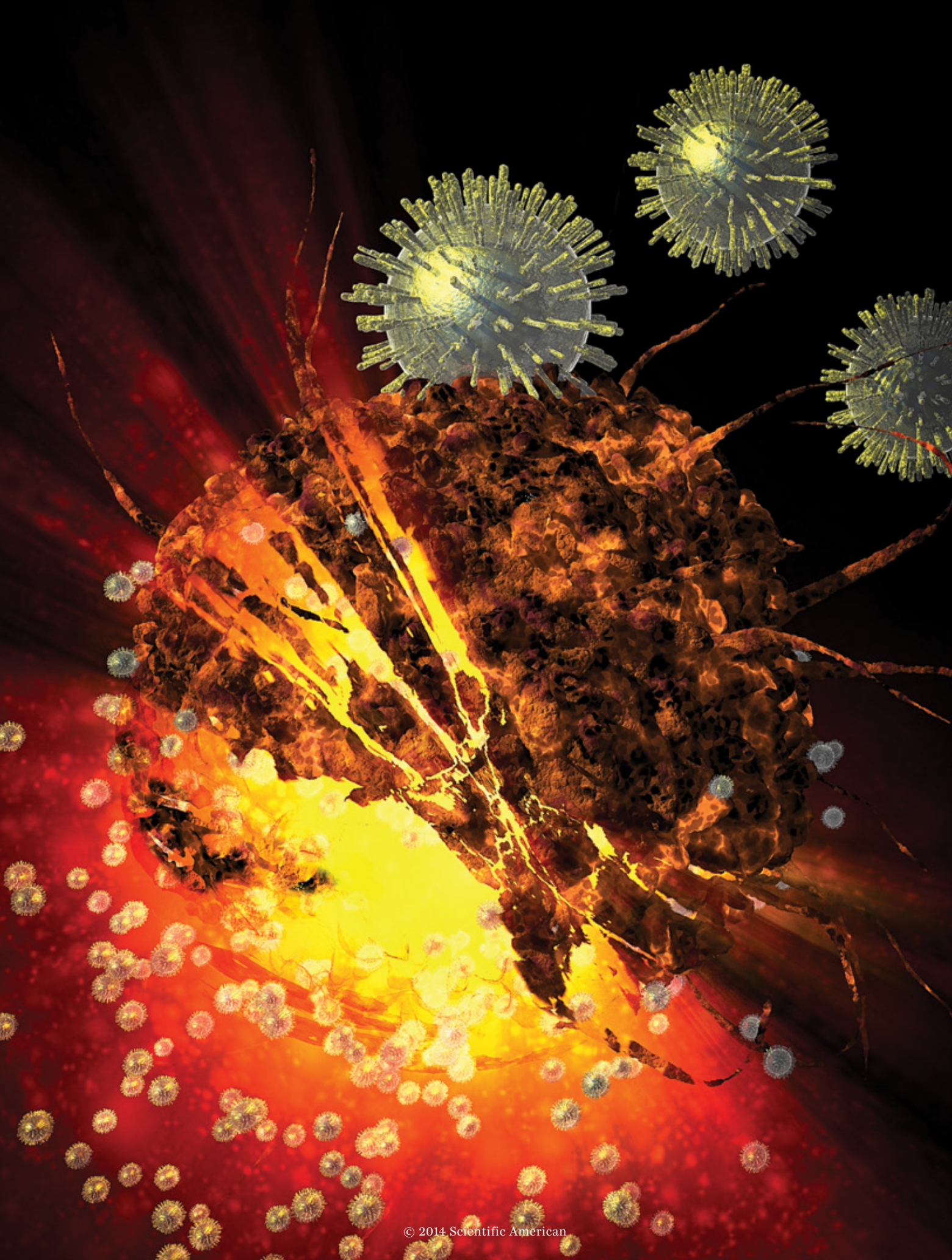
MEDICINE

For some cancer patients, viruses engineered to zero in on tumor cells work like a wonder drug. The task now is to build on this success

VIRUS THERAPY FOR CANCER

By Douglas J. Mahoney, David F. Stojdl and Gordon Laird

Illustration by GUYCO



Douglas J. Mahoney is an assistant professor in the department of microbiology, immunology and infectious disease at the University of Calgary.

David F. Stojdl is an associate professor in the departments of pediatrics and of biochemistry, microbiology and immunology at the University of Ottawa and a senior scientist at the Children's Hospital of Eastern Ontario Research Institute. He also co-founded a cancer virotherapy company that was recently sold to SillaJen.

Gordon Laird is a writer whose articles and commentary have been featured on CNN, the BBC, NPR and other outlets. He has won several National Magazine Awards.

IN 1904 A WOMAN IN ITALY CONFRONTED two life-threatening events: first, diagnosis with cancer of the uterine cervix, then a dog bite. Doctors delivered the rabies vaccine for the bite, and subsequently her "enormously large" tumor disappeared ("*il tumore non esisteva più*"). The woman lived cancer-free until 1912. Soon thereafter several other Italian patients with cervical cancer also received the vaccine—a live rabies virus that had been weakened. As reported by Nicola De Pace in 1910, tumors in some patients shrank, presumably because the virus somehow killed the cancer. All eventually relapsed and died, however.

Even though the patients perished, the notion of treating cancer with viruses able to kill malignant cells—now termed oncolytic virotherapy—was born. And investigators had some success in laboratory animals. Yet for a long time only partial responses and rare cures in human trials ensured that the field stayed at the fringes of cancer research. Viral therapy for cancer faced several additional hurdles: uncertainty about its mechanisms and how to use viruses to achieve cures, a dearth of tools with which to engineer more effective viral strains and the habitual reluctance of physicians to infect patients with pathogens. Doctors elected to use poisons (chemotherapy) instead of microbes—mostly because they were more comfortable with those drugs and understood them better.

The story is very different today. Starting in the 1990s, researchers armed with a richer understanding of cancer and viruses and with tools for manipulating genes began to uncover the details of how viruses attack cancer cells. Investigators also started devising ways to genetically alter viruses to enhance their cancer-killing prowess and to prevent them from causing unwanted effects.

That work is beginning to pay off. One oncolytic virus was approved in China for head and neck cancer in 2005, and nearly a dozen are now in various stages of human testing in a wide variety of cancers. Recent results from the virus furthest along in testing give researchers hope that the U.S. Food and Drug Administration will approve one or more viruses as cancer therapies within a couple of years.

In particular, findings presented at the annual meeting of the American Society of Clinical Oncology in June 2013 showed that 11 percent of patients in a large trial of virotherapy against advanced metastatic melanoma (a skin cancer) had a "complete response"—showed no sign of the cancer—after treatment. The medicine, named T-VEC, consists of a version of the herpes simplex virus genetically altered to hit cancer with a double whammy—both to destroy cancer cells directly and to produce a protein (GM-CSF) meant to spur the immune system to also attack the cancer. In contrast to the side effects of many cancer therapies, the worst ones the virus caused in the study were flulike symptoms such as fatigue, chills and fever. Amgen, which makes the drug, released data on overall survival in November 2013 and the spring of 2014. Patients taking T-VEC gained four months over those taking GM-CSF alone.

The survival data may seem disappointing. Yet investigators are heartened that one in 10 patients had a complete response. The complete response rates achieved by T-VEC surpassed those of all recently approved drugs for metastatic melanoma, including a drug called vemurafenib, which was approved in 2011 to treat that cancer after a study reported in the *New England Journal of Medicine* determined that all signs of cancer disappeared in a much smaller ratio of patients—less than 1 percent.

Most encouraging, in the case of T-VEC, is a 2009 report showing that close to 90 percent of patients who responded to the therapy were alive more than three years later. A New Jersey woman named Sue Bohlin, for example, had no luck with standard treatments for her melanoma, and the cancer continued to spread, so she enrolled in a clinical trial of T-VEC. Three years after treatment with the drug, the now 61-year-old Bohlin remains cancer-free. "I'm one of the lucky ones," she says. "It's been a wonder drug for me."

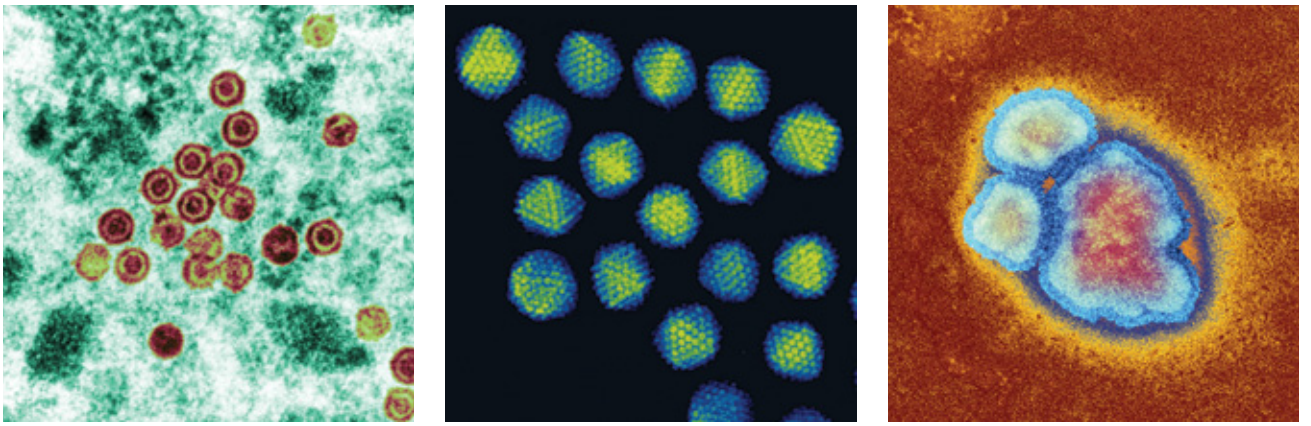
IN BRIEF

Specially engineered viruses could potentially infect and destroy human cancers without appreciably harming healthy tissues.

Once inside a tumor, such "oncolytic" viruses replicate extensively, yielding an army of virus clones able to seek out and infect more of the cancer cells.

Nearly a dozen viruses are being tested in humans as stand-alone therapies or in combination with existing treatments; several are in late-stage clinical evaluation.

Early on researchers attempted to suppress the immune system, to give the viruses time to act on the cancer cells before they were attacked as foreign. In an about-face, they are now engineering viruses to reawaken the immune system to fight the tumor.



PROGRAMMED CANCER KILLERS: **Herpes simplex virus, adenovirus and measles (*left to right*) are three of about a dozen viruses that are being engineered to infect and kill cancer cells and, in some cases, boost the immune system's response to the disease.**

The goal, of course, is to make Bohlin's experience the norm so that more than 11 percent of patients see their cancer disappear. Some of the viruses in clinical trials could well do that. Meanwhile researchers, including two of us (Stojdl and Mahoney), continue to explore ways to make virotherapy more effective for more people.

PROGRAMMABLE BIOLOGICAL MACHINES

VIRUSES OFFER a number of features that are appealing for cancer therapy, and scientists are trying to enhance several of them to improve their potency and safety. For one, certain viruses—either on their own or with some prodding—will selectively infect cancer cells while ignoring normal cells or will grow well only in cancer cells, leaving healthy cells relatively unscathed. Such selectivity is important for minimizing side effects, which are mainly caused by damage to normal tissues.

Once inside a cancer cell, viruses can be powerful killing machines. No virus can reproduce on its own, but if it finds the right conditions in a cell, it can hijack that cell's gene-copying and protein-making machinery to make new copies of itself. If all goes well in the case of cancer treatment, a virus will generate an army of clones that charge out of the infected tumor cell to seek and infect neighboring or even distant cancer cells. At times, the escaping viruses literally blow apart an infected cell as they exit—a process known as cell lysis—hence the name "oncolytic" virotherapy. In other cases, the viruses kill more stealthily, subtly programming a tumor cell to initiate a self-destruct sequence, called cell suicide, or apoptosis. In essence, viruses delivered as a drug convert infected cells into factories within the body that churn out more and more drug, then close for business.

Another advantageous component of virotherapy is its multipronged approach to attacking a cancer. Many cancer drugs interfere with only one aspect of cell functioning, a common drawback because malignant cells often eventually find ways of compensating for the effect. Also, cancers are really an ecosystem of cells that all descend from one deranged ancestral cell but now possess different genetic and other aberrations—so a drug that works on some cells may not work on others. These are two reasons why cancers become resistant to treatment, allowing tumors to rebound and kill patients. For such reasons, physicians often attack cancer from multiple angles with more than one kind of treatment, much as doctors treat patients with HIV today. Virotherapy, by itself, is more akin to combination than single therapy because viruses disrupt many processes in the cell at once so that the cell is less likely to become resistant.

Beyond directly destroying tumor cells, when a virus infects a cell, it elicits several "bystander" mechanisms that can kill cancer cells that have resisted infection, including so-called vascular collapse [*see box on next page*]. Whereas oncolytic viruses are predominantly selective for tumor cells, some strains also infect tumor blood vessels. This secondary infection, in turn, attracts immune cells that damage the blood vessels, choking off blood flow to the tumor. Another important mechanism involves the rapid recruitment of immune cells to the tumor to fight off the initial infection. This immune response has long been viewed as a major impediment to successful virotherapy; after all, a prompt, strong attack should, in theory, erase virus-infected cells before the microorganisms have a chance to reach many cells. In fact, early efforts focused on keeping the immune system at bay to give the virus time to infiltrate the tumor.

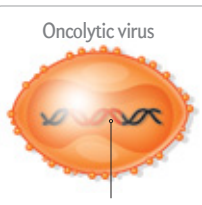
Yet more recent work has shown that these immune cells sometimes get redirected toward the cancer itself and are, in many cases, critical for therapeutic success. Although we do not know the full details of how, when and why this switchover occurs, we do know that the process of infecting and killing tumor cells generates cellular debris that induces the production of small immune-stimulating molecules called cytokines and also activates the immune system's dendritic cells. Dendritic cells normally survey the body for any entities not native to the body and alert the immune system's T cells to mount a response against the apparent invader. In this case, the dendritic cells are thought to treat tumor components as "foreign" and to awaken the immune system to the fact that there is a tumor growing.

In addition to all these potential benefits, viruses can be programmed to behave in ways that natural viruses would not: they can be genetically altered to, for instance, decrease their ability to reproduce in healthy cells and increase their selective replication in cancer cells. The virus's genome can also be revised to give the viruses other cancer-fighting traits, such as the T-VEC virus's ability to pump up the body's immune attack against a tumor.

SCIENCE SOURCE

How Oncolytic Viruses Destroy Tumors

Not all viruses attack cancer cells, but some are especially good at targeting tumors and ignoring healthy tissues. Researchers are learning how to modify these viruses (*inset at left*) to awaken a stronger immune response against the tumor (*below*). Ideally, this approach would be paired with new treatments (*not shown*) that block a tumor's ability to suppress the immune system.



Researchers can insert genes for tumor antigens—molecules that elicit immune responses—into viruses. Infected tumor cells then produce the antigens, enhancing immune activity against such cells.

Blood vessel
Replicating virus
Tumor cell lysis (*dark gray*)
Infected tumor cell
Tumor cells
Oncolytic virus

Direct Killing (Lysis) of Cancer Cells

Once inside a cancer cell, the virus forces it to make many more viruses. This new viral army charges out of the infected cell, killing it, and seeks out new cancer cells to infect. Or the viruses may simply reprogram infected tumor cells to self-destruct in a process known as apoptosis.

Vascular Collapse

Viruses also infect the cells that line the blood vessels around the tumor. As those cells die, they begin attracting the attention of white blood cells called neutrophils, which help to trigger the production of blood clots, leading to the eventual collapse of the blood vessel and the choking off of the tumor's nutrient supply.

Neutrophil
Infected endothelial cell
Infected tumor cell
Antigen
Danger signals and cytokines
Clotted blood
Tumor cell apoptosis
Tumor cell apoptosis
Dendritic cell
Activated T cell
T cell
Dendritic cell
Tumor antigen
Natural killer cell
Natural killer cell
Dead tumor cell
Vascular collapse
To distant tumors
Lymph nodes of the immune system

Adaptive Immune Response

When an infected cancer cell bursts, it releases antigens—including the engineered antigens—which are engulfed by dendritic cells of the immune system. These antigens in turn are presented to the body's T cells, which go hunting for other cancer cells that share the same antigen.

Innate Immune Response

The death of virus-infected cells spurs the release of immune-stimulating molecules—including danger signals and cytokines—which prompt natural killer cells to destroy other infected or noninfected tumor cells.

SOURCE: "TARGETED AND ARMED ONCOLYTIC POXVIRUSES: A NOVEL MULTI-MECHANISTIC THERAPEUTIC CLASS FOR CANCER," BY DAVID H. KIRN AND STEVE H. THORNE, IN *NATURE REVIEWS CANCER*, VOL. 9; JANUARY 2009

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Illustration by Tami Tolpa

SUPERVIRUSES

RESEARCHERS ARE EXPLOITING all this knowledge to enhance virotherapy in several ways, some of which are being tested in clinical trials now under way. One approach aims to engineer viruses to home in on certain molecules known as receptors that occur in greater quantities on cancer cells than on normal cells. Attachment to these receptors helps viruses to enter cells. This engineering should therefore help ensure that much more virus is taken up by cancer cells than by their healthy cousins.

A second, more advanced approach aims to enhance the tendency of viruses to replicate best in cancer cells. Because malignant cells replicate constantly, they generate a great deal of raw material. Viruses need these raw materials as well, and so they will often proliferate, or grow, better in a malignant cell than in other cells they manage to enter. Knowing of this proclivity, scientists have engineered viruses that are hyperresponsive to the raw materials present in excessive amounts in tumor cells. For example, they can genetically alter a virus so that it cannot direct the production of thymidine, a building block of DNA. Without this ability, the virus is forced to find an outside source of thymidine, and tumor cells have plenty. Normal cells do not offer enough thymidine for the virus to replicate. This approach is in early and midstage clinical testing.

John Bell's group at the Ottawa Hospital Research Institute (in which Stojdl was a postdoctoral researcher) and Glen Barber's group at the University of Miami have identified another reason that viruses can thrive in cancer cells: as cells undergo genetic and other changes that push them toward malignancy, they often lose some of their defenses against microbial attack, such as the ability to produce an antiviral molecule called interferon. These groups and others have taken advantage of this weakness to design viruses, such as an engineered version of vesicular stomatitis virus (VSV), that will not grow in any cell except tumors with defects in their antiviral defenses. One of these VSVs is being evaluated in patients with liver cancer.

To us and many of our colleagues, the greatest gains are going to come if we can enhance the ability of viruses to elicit immune responses against tumors. In the T-VEC trials, investigators found that the virus did not reach every metastatic cancer cell that had spread away from the primary tumor. Even so, 11 percent of patients experienced a complete response—no sign of cancer anywhere in the body—presumably because the engineered virus stimulated the immune system to seek out and destroy cells that the virus did not reach. In support of this possibility, the researchers found activated T cells at sites of metastases.

In another immunity-related strategy, pioneered by our colleagues at McMaster University in Ontario and the Mayo Clinic in Rochester, Minn., Stojdl is engineering into therapeutic viruses genes that encode molecules called tumor antigens that can elicit an immune response when present on tumor cells (for example, melanoma-associated antigen, or MAGE). In treated animals, the antigens are displayed to the immune system, prompting it to home in on and kill cancer cells at the same time that the oncolytic virus both kills cancer cells directly and changes the tumor microenvironment in a way that awakens other antitumor immune responses. Human studies are expected to start this year.

The idea of revving up the immune system is promising. But we have learned an important lesson from decades of immunotherapy research: tumors have evolved many ways to evade immune attack, and co-treating patients with other agents that relieve the immune suppression within the tumor may also be needed. It does not matter how much we boost the immune system if the tumor is highly adept at tamping down the response.

With colleagues at the University of Calgary, one of us (Mahoney) is trying to shut down the immune-suppressing cells that are known to lurk within tumors at the same time as patients receive oncolytic viruses. With those cells under wraps, the immune system activated by the virus should be able to escape suppression and thus fight cancers more effectively. By targeting the suppressor cells, we are taking advantage of decades of work by other researchers who have been designing molecules able to target and shut down immunosuppression; such drugs, including monoclonal antibodies that latch onto a molecule called PD-1, are among the most promising next-generation cancer therapies. Almost certainly such combination strategies, as well as deploying viruses together with traditional approaches, will be the future of oncolytic virus therapy because of their potential to help patients who do not respond to stand-alone virus treatment.

As we consider combination treatments, however, we must be careful. Although virotherapy has so far proved to be safe in clinical trials—there have been very few serious adverse events reported in patients, which contrasts sharply with most other experimental cancer medicines—we cannot be sure how our viruses will behave when combined with other, complementary immunotherapy strategies or when we increase the dose. "Oncolytic virotherapy has been very safe so far," says our colleague Stephen Russell, a professor of medicine at the Mayo Clinic. "But as we work toward increasing its potency and broadening its utility—particularly in the context of modulating host immunity—we run the risk of introducing toxicity, and we need to be aware of that," he cautions.

Harnessing the power of viruses to treat cancer has been a long work in progress. As the result of decades of research into molecular genetics, cancer biology, tumor immunology, immunotherapy, virology and gene therapy, investigators finally have the collective tool set and knowledge they need to exploit these interactions between viruses and the body for cancer therapy. That oncolytic virus therapy can work has been proved. The question now is how to make it work for more patients and to finally realize the promise of De Pace's 100-year-old dream of putting viruses to good use by saving the lives of people with cancer. SA

MORE TO EXPLORE

Novel Oncolytic Viruses: Riding High on the Next Wave? Marianne M. Stanford et al. in *Cytokine & Growth Factor Reviews,* Vol. 21, Nos. 2–3, pages 177–183; April–June 2010.

Thunder and Lightning: Immunotherapy and Oncolytic Viruses Collide. Alan Melcher et al. in *Molecular Therapy,* Vol. 19, No. 6, pages 1008–1016; June 2011.

The Emerging Role of Viruses in the Treatment of Solid Tumours. M. G. Bourke et al. in *Cancer Treatment Reviews,* Vol. 37, No. 8, pages 618–632; December 2011.

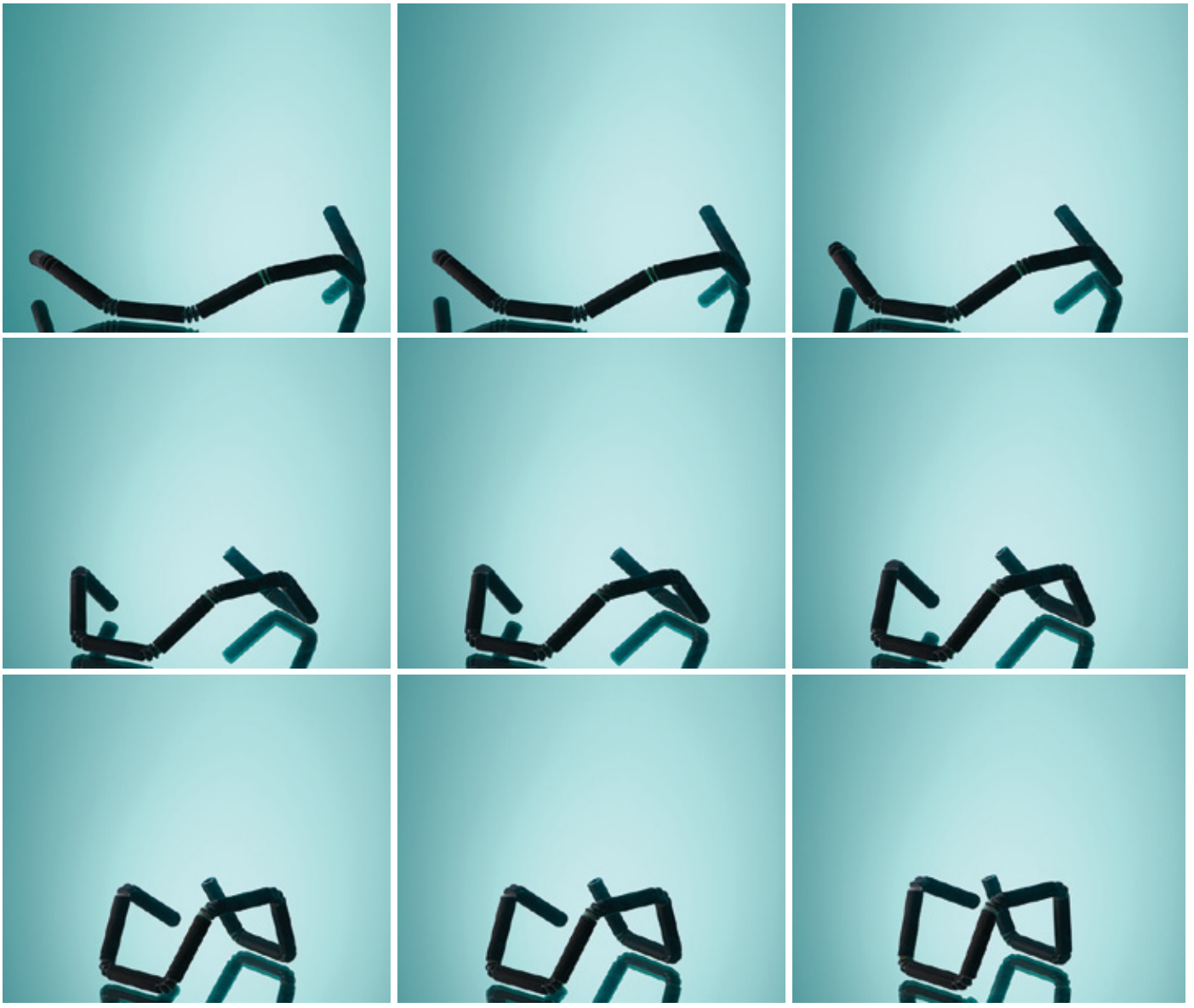
Virotherapy—Cancer Targeted Pharmacology. Alison Tedcastle et al. in *Drug Discovery Today,* Vol. 17, Nos. 5–6, pages 215–220; March 2012.

A list of clinical trials involving oncolytic virotherapies: http://clinicaltrials.gov/ct2/results?term=oncolytic+virus&Search=Search

FROM OUR ARCHIVES

Cancer's Off Switch. Jedd D. Wolchok; May 2014.

The Progra World

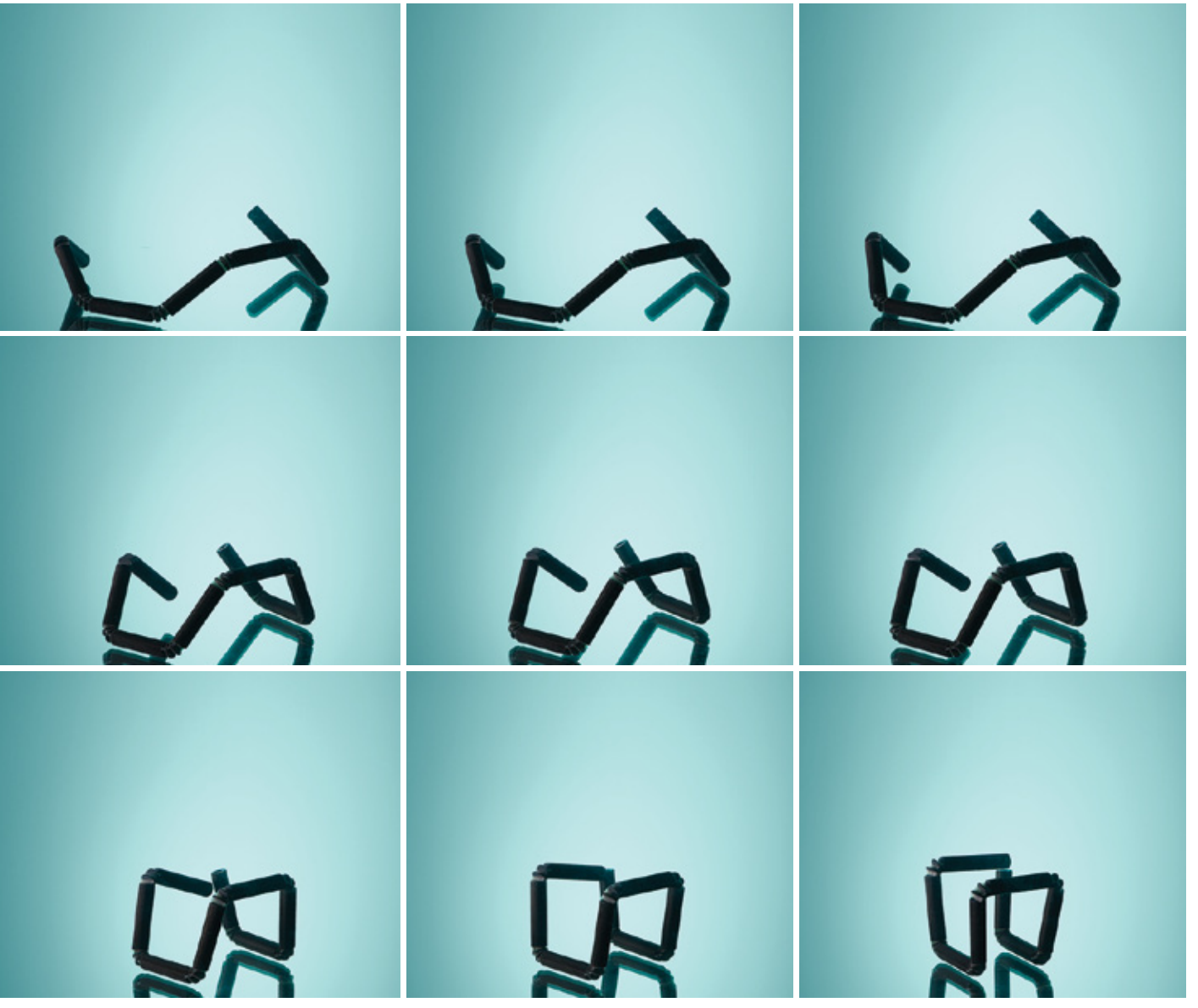


Photographs by Travis Rathbone

mmable

Novel materials, 3-D printers and a new way of thinking about design could yield objects capable of assembling themselves and changing shape or function on command

By Thomas A. Campbell, Skylar Tibbits and Banning Garrett



"PROGRAMMED" OBJECTS such as the 3-D-printed polymer strand above, which folds into a wire-frame cube when submerged in water, change form or function when exposed to a trigger.

Thomas A. Campbell is a research associate professor at the Institute for Critical Technology and Applied Science at Virginia Tech and a nonresident senior fellow at the Atlantic Council.

Skylar Tibbits is director of the Self-Assembly Lab and a research scientist in the department of architecture at the Massachusetts Institute of Technology.

Banning Garrett is a Washington, D.C.–based strategic policy analyst who explores long-term global trends and the impact of technology on society. He has written for more than 20 journals and media outlets.

The road to self-assembling houses and shape-shifting robots could begin with something as simple as plumbing. Today when we want to build infrastructure for moving water around a city, we take rigid pipes with fixed capacities and then bury them. And the system works well enough—until we need to increase the flow of water to an area or until a pipe breaks. Then we have to dig the whole thing up and replace it.

A nice alternative would be flexible pipes that could change shape on command or under the right level of pressure or pipes that could heal themselves in the event of a rupture. Advances in computer-aided design (CAD) and materials science are now making such pipes feasible. Those same advances and the new form of design that they have made possible could yield a world of programmable matter—material objects capable of self-assembling, morphing into new shapes or changing properties on command.

Scientists are already building self-assembling machines, but they are tiny—nanoscale devices that work as biochemical sensors, electronics or drug-delivery carriers. We are interested in what happens when programmable matter achieves human scale. There are two primary ways to achieve this goal. One approach involves creating unconnected building blocks that can come together or break apart autonomously to form larger programmable structures. Another tack is to build shape-changing objects as a single, complete structure—objects with hinges, stress points or electronics embedded in just the right spots to allow them to change shape under desired circumstances. We call this second approach 4-D printing. As with 3-D printing, 4-D printing involves constructing preconnected objects by laying down layer after layer of material. In this case, however, those objects can change shape or properties over time after they are printed.

Programmable matter could yield objects that save materials, energy and labor. Think of a chair that can turn itself into a table. Think about those flexible, self-healing water pipes. It could make it possible to build complex machines without human construction. Such systems would be particularly valuable in hostile environments, such as outer space. One could launch a small, compressed box into space that, on reaching orbit, would reconfigure itself into a functional satellite. Other space-bound devices could be configured to serve multiple purposes—for example, a solar array could be made to transform into a parabolic antenna or a storage capsule.

But programmable matter could also generate new uncertainties. Imagine a material world that could be hacked. Morphable airplane wings could be sabotaged. Buildings could be commanded to disassemble with people inside. Intellectual-property rights could also become more complex as products began to shape-shift from one form to another, creating patent issues that the U.S. Patent and Trademark Office has never even remotely considered. The existence of such risks is all the more reason to begin the discussion of this potentially transformative technology now, so that solutions, control measures and policies can be built in from the beginning.

NO ASSEMBLY REQUIRED

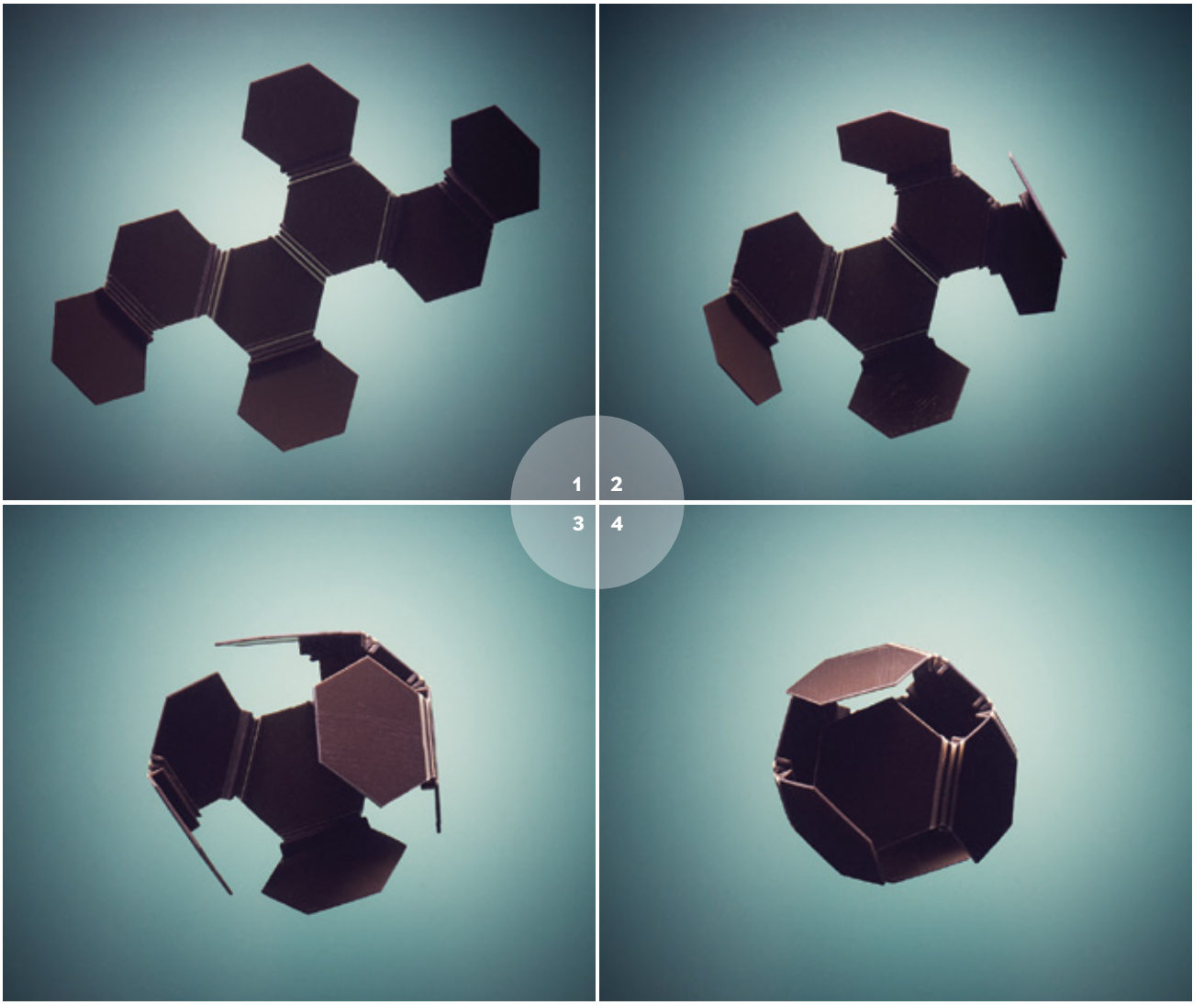
A HANDFUL OF IMAGINATIVE SCIENTISTS have been talking about programmable matter since the early 1990s, but the field received its big boost in 2007, when the U.S. Defense Advanced Research Projects Agency funded a Programmable Matter project. DARPA laid out a multiyear plan for designing and constructing microscale robotics systems that could morph into larger military systems such as physical displays and specialized antennas. Researchers shrank robotics to the millimeter scale, around the

IN BRIEF

The science of programmable matter focuses on the engineering and design of objects that can change form or function in an intentional, programmable fashion.

An outgrowth of additive manufacturing, or 3-D printing, programmable matter could yield shape-shifting robots, self-deploying satellites, and self-assembling furniture or even buildings.

But devices made this way could also be vulnerable to hacking and sabotage. Moreover, products that can transform from one device into another could create significant intellectual-property issues.



SELF-FOLDING DEVICES rely on materials, placed at points of motion, that expand or contract when they come into contact with heat, light, electricity or other triggers. This self-assembling octahedron (*above*) takes shape when placed in water.

width of a pencil. Within a few years they had succeeded in demonstrating tiny, shape-shifting robots.

One of us (Tibbits) has been working on ways to use 4-D printing to build such machines without the robotic mechanisms (motors, wires and electronics). At the Massachusetts Institute of Technology's Self-Assembly Lab, he and his colleagues have fashioned, among other things, a snakelike object, made of a special polymer, that folds to form the letters "MIT" when inserted into water; a single strand of polymer that self-transforms from those letters into the letters "SAL" (for Self-Assembly Lab); a flat surface that self-folds into a truncated octahedron; and a flat disk that, when exposed to water, folds into a curved-crease origami structure.

Christopher B. Williams of Virginia Tech has embedded alloy wires and printed circuits into special compliant structures as they are being printed. Once printing is complete, an external signal can be applied to trigger actuation of the compliant structure, changing the shape of the object. This approach has potential implications for robotics, furniture assembly and building construction.

Williams and one of us (Campbell) have gone further and merged 4-D printing with nanomaterials. The insertion of nanomaterials into printed objects can create multifunctional nanocomposites that can change properties in response to electromagnetic waves (visible light and ultraviolet light). For example, this group printed a Virginia Tech logo with embedded nanomaterials that change color under different lighting. With further development, materials such as these could lead to a new class of sensors, which could be embedded in medical devices to test for extremes in blood pressure, insulin levels and other medical metrics.

A COMPUTATIONAL CHALLENGE

THESE DAYS IT IS EASY to print a static "MIT" or "Virginia Tech" logo: simply feed the instructions for the object you want into a 3-D printer. But printing objects that can later change shape in-

volves designing programmable characteristics such as stress and flex points or embedded nanomaterials into the object. This kind of engineering presents thorny computational challenges beyond the abilities of today's CAD software.

Say you want to print something that transforms from a table into a chair. Topologically there are many ways for a table to fold into a chair. Most of those ways will not work in the real world, however, because in the process of folding, the object will hit itself or become tangled up in itself. Finding the best solution is a complex simulation challenge. Researchers have developed a library of physical mechanisms that form the basis for any object we want to design—mechanisms for folding, stretching, twisting, shrinking, and so on. The object's transformation depends on the collective action of those building blocks. We can design objects in a linear fashion—*fold, fold, stretch*—or we can program them according to logic—*if this happens, do this; if that happens, do that.*

These combinations quickly become so complex that it is difficult to predict their behavior, which is why developing new types of design software is the first step in making programmable matter a reality. Designers need computers to simulate the transformations of 4-D-printed objects and to translate their designs into instructions that a printer will understand. They need software that can help them avoid problems that are hard to foresee—such as an object getting tangled up in itself when it changes shape. As a first step toward this goal, Tibbits's group worked with the design software firm Autodesk to develop Project Cyborg, which simulates and optimizes the dynamics of 4-D-printed objects. Using Cyborg for design, a multimaterial 3-D printer built by the company Stratasys and a new, Stratasys-developed polymer that expands by 150 percent when submerged in water, Tibbits's group created the self-folding M.I.T. logo and other 4-D-printed objects.

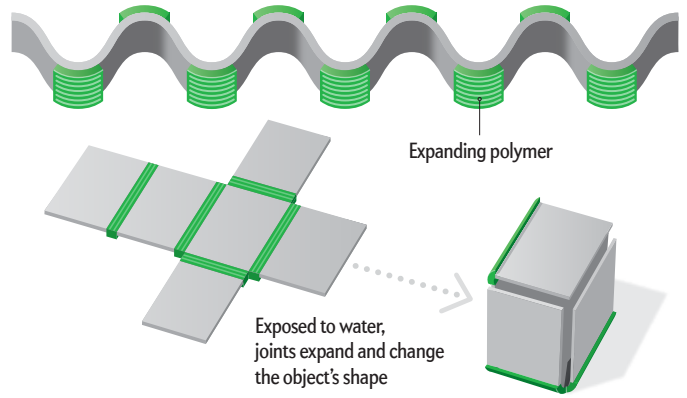
So far most of the objects that programmable matter researchers have designed have been fairly simple, involving more or less one type of joint and two materials. But the materials already exist to build more complex devices, and once we increase that variety further, we are limited only by our computational ability, our imagination and the laws of physics.

BASICS

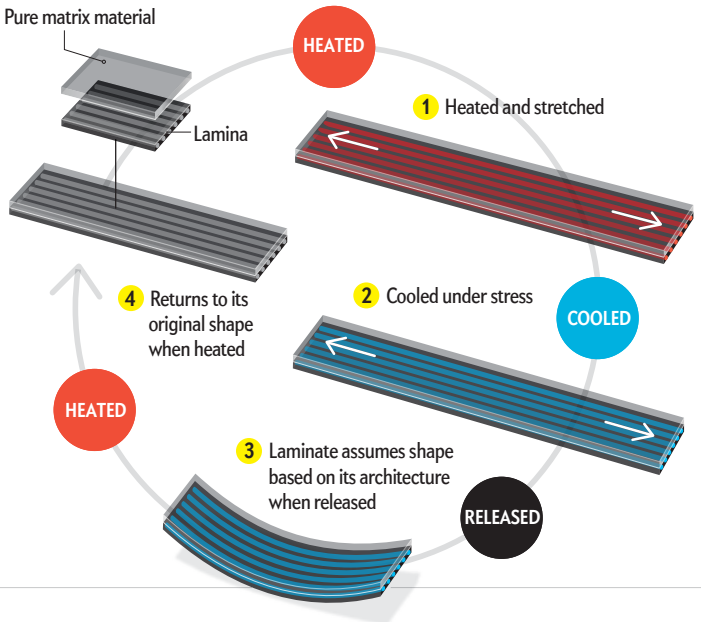
4-D Printing

There is more than one way to program matter. One of the authors (Tibbits) has used 3-D printers to create objects whose components are connected by a polymer that expands when exposed to water (*a*). That expansion turns a flat strip into an undulating wave or a two-dimensional group of squares into a cube. H. Jerry Qi and Qi Ge, both then at the University of Colorado, and Martin L. Dunn of the Singapore University of Technology and Design have used 3-D printers to make multimaterial objects that change shape when heated or cooled (*b*).

a Hydromechanics



b Thermomechanics



SOURCE: "ACTIVE MATERIALS BY FOUR-DIMENSION PRINTING," BY Q. GE, H. JERRY QI AND MARTIN L. DUNN, IN *APPLIED PHYSICS LETTERS*, VOL. 103, NO. 13; 2013

BUILDING BLOCKS

A USEFUL CONCEPTUAL TOOL for thinking about programmable matter is the "voxel," or volumetric pixel. In computing, a voxel is a pixel in three-dimensional space. In programmable matter, a voxel is a fundamental unit from which complex devices could be built. A voxel could be a synthetic particle of varying size made from materials ranging from silicon to ceramics to plastics to titanium. Voxels could be tailored to behave as any one of a wide range of subsystems—an energy-storage device, an actuator, a sensor, a conductor, an insulator, a protective shell, an antenna or even a microcomputer. Voxels could be assembled and, together, programmed to change shape or function and collectively form different objects.

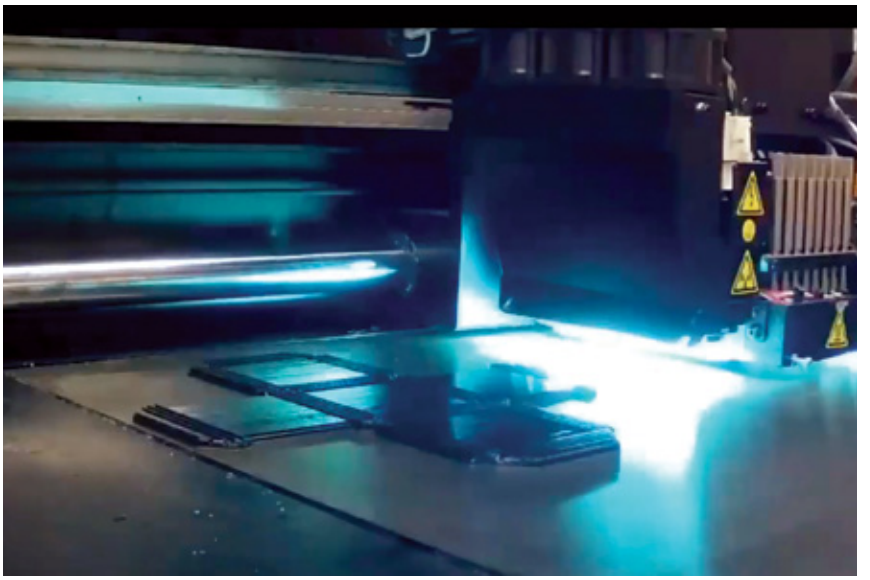
In their recent book *Fabricated: The New World of 3D Printing,* Hod Lipson and Melba Kurman use voxels to draw an analogy between programmed matter and biological life. The many proteins in living things are, after all, made of 22 building blocks—amino acids. "If fewer than two dozen element

SCIENTIFIC AMERICAN ONLINE For more on programmable matter, go to ScientificAmerican.com/nov2014/4-d-printing

Illustration by John Grimwade

types give rise to all biological life, a few basic voxel types can also open a large range of possibilities," Lipson and Kurman write. There could be hard and soft voxels, conductive voxels for wiring, electrical circuits composed of resistor, capacitor, inductor and transistor voxels. "Add actuator and sensor voxels," they add, "and you have robots."

Robots of this sort are of great interest to the U.S. military. The U.S. Army and Navy are already developing ways to 3-D print spare parts on ships or in the field because avoiding the transport and storage of thousands of spare parts could save time, expense and space. Programmable matter could amplify those benefits. Imagine having a bucket of voxels on a submarine. If a part breaks or you need a specific tool, you simply take a collection of voxels and program them to form that tool. When the tool is no longer needed, you command it to disassemble, leaving the voxels available for making other tools or parts.



3-D PRINTERS such as Stratasys's Objet500 Connex multimaterial printer can embed expanding polymers and other functional materials at the time of manufacture.

Beyond parts and tools, programmable matter could provide uniforms that adjust insulation and cooling to the surrounding environment and the biometrics of the individual. This year the army invested nearly $1 million in a project that would use 4-D printing to create dynamic camouflage. Think very long term—and use a fair bit of imagination—and it is conceivable that programmable matter could be used to build morphable robots that can shape-shift around and through obstacles, similar to the T-1000 robot in the movie *Terminator 2*.

Programmable matter could one day be used in large-scale construction, both in military and in civilian contexts. Consider the possibility of self-assembling buildings. Instead of casting brick or pouring concrete, we pour a building-size volume of programmable matter into a foundation and then tell the elements to "grow" or "stabilize" into a finished structure, complete with electricity and plumbing. This might seem unnecessarily complicated for your average new-home construction, but in hostile environments—say, in a war zone or on the surface of Mars—self-assembly becomes attractive.

THE SELF-ASSEMBLING FUTURE

WE HAVE MENTIONED only a handful of the ways in which programmable-matter researchers might one day deploy their inventions. How about airplane wings that change shape in response to shifting air pressure or temperature? Or tires whose gripping surface changes depending on road and weather conditions? Self-healing materials could protect aircraft or help bridges adapt to sudden increases in traffic or even earthquakes. And what about self-assembling furniture? Anyone who has shopped at Ikea would appreciate a new dresser that is packaged flat but automatically folds into shape on command.

These concepts might sound magical, but they are grounded in real engineering and science research. Yet big hurdles remain. In addition to the computation challenge it poses, programmable matter will push the limits of materials science and manufacturing. To create those self-folding M.I.T. and light-sensitive Virginia Tech logos, we needed entirely new polymers. What types of new materials will it take to build a self-assembling house or a morphing airplane wing? Once the building blocks have been developed, we still face the challenge of assembling them into large, complex objects. How do we make voxels stick together? How should we program them, and what types of energy can they use to self-assemble?

Assuming we are successful in solving these problems, we will still face the challenges mentioned earlier, including exposure to hacking and complicated intellectual-property issues. We should soon have the opportunity to work through these challenges. For the past year and a half Tibbits has been working with several companies to develop shape-shifting materials, products and construction systems, and Campbell and Williams have been in discussions with a company to apply 4-D printing with nanomaterials as an anticounterfeiting system. The self-assembling house might not be as far off as it seems. SA

MORE TO EXPLORE

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COURTESY OF SELF-ASSEMBLY LAB AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY, STRATASYS, LTD., AND AUTODESK, INC.

ENERGY

SOLAR WARS

The growing popularity of solar power on rooftops spurs a utility backlash

By David Biello

Every six months or so Doug Cox washes his roof so he can make more electricity. The 16 solar panels on the southern face can produce nearly four kilowatts of electricity in the strong Phoenix sunshine—enough to offset much of the power required to cool his home in this hot climate. But the two-year-old system gets dusty, which slows the current flow. "My wife is up there, hosing the soap off as I'm scrubbing," says Cox, a 37-year-old high school math teacher. "We've even had our five-year-old daughter help us. She's on the ground, and we tell her when to turn the hose on and off."

Illustration by Zohar Lazar

The Cox family is part of a growing trend in Phoenix and other sunny locales: homeowners using rooftop solar panels to generate their own power and sell the excess to the local electric utility grid. More than 127,000 homes in Arizona now have rooftop arrays. The Coxes bought their panels outright, after doing the math that proved that the system—with a life of 20 years or more—would pay for the $12,000 cost in roughly six years, through savings on their electricity bill and tax breaks. "Last year, in May, June and July, we had a zero utility bill, which is awesome to see," Cox recalls. Other months the Cox household produces excess power, which gets sent to the local grid for credits on future bills. "Our meter goes backward," he says.

To Arizona Public Service (APS), the Phoenix-area utility, however, Cox is a freeloader. By not paying for as much electricity, it says, the family is not covering its share of the cost of maintaining the region's power grid that their home still uses. Each solar home, APS claims, imposes an economic burden that amounts to as much as $1,000 a year on other households without solar panels. To make up the shortfall, APS proposed a surcharge of up to $100 per month for each solar homeowner. And to convince the public why the charge was necessary, APS, backed by utility interest groups, went on an advertising spree. In 2013 it spent nearly $4 million on television, print and Internet ads. Solar power, it seems, is so successful in Arizona that the utility sees it as an existential threat.

Solar customers pushed back, calling the proposed surcharge a "sun tax." They said the electricity industry needs competition, and they did their best to mount a public relations counteroffensive, including enlisting some unexpected allies. "Why should [utilities] be allowed to hold the monopoly on this power source?" asked Tom Morrissey, former chair of the Republican Party in Arizona. "Why can't we provide for ourselves while easing the burden on the power grid?"

The emerging war between utilities and solar customers reveals a fundamental shift in electric grid economics. Cheap solar panels from China, combined with federal and state incentives, have brought solar from a niche pursuit to a significant force for change in the power industry, significant enough to threaten the utility as it has existed for the past 100 years. This fight between homeowners and industry could wind up reconfiguring the political landscape, uniting environmentalists and Tea Partiers and perhaps dividing the Republican Party. What may emerge could be the beginning of a new business model for the power grid—and a new form of political power in suburbia.

David Biello is an associate editor at *Scientific American* and frequently covers energy and environmental issues.

CHEAP TO BUY, CHEAPER TO RENT

THE U.S. SOLAR WAR will be won or lost on price, and solar is currently cheap and getting cheaper. Installation companies can buy solar modules in bulk for as little as 60 cents per watt, half the cost of just five years ago. Solar, once all financial factors are included, is now as cheap as grid electricity wherever residential rates are 15 cents per kilowatt-hour or more—roughly 16 percent of the U.S. retail electricity market. More than 100,000 American houses went solar just in 2013, according to the Solar Energy Industries Association. The challenge of solar technology expense has been overcome, says David Crane, CEO of NRG Energy, a nationwide utility that has fossil-fuel and nuclear power but also large solar power plants. All that is left to tip the balance in favor of rooftop systems is what he calls "friction costs."

By that Crane means the cost of finding a solar panel maker and installer, filing paperwork with state and local authorities as well as the local utility, and installing the solar array properly and safely. Those steps can at least double the cost of a residential system, to as much as $5,000 per kilowatt. A typical home in the U.S. installs four to six kilowatts of panels, offsetting roughly half the home's electricity use.

But the friction cost is coming down, too—in some cases to zero, as far as the homeowner is concerned—thanks to companies that essentially rent and install the equipment, such as SolarCity, Sungevity, Sunrun and Vivint. Utilities themselves sometimes offer something similar, dubbed "community solar." The contracts differ, but essentially the companies pay to install solar panels on a roof and reap any attendant tax credits and other incentives. Homeowners pay a lease price and a set rate for the electricity, resulting in a total bill that is less than their current electric bill. Most of the leases run for 20 years and include maintenance.

The idea is to remove the "stigma" that solar is expensive, in the words of Lyndon Rive, CEO of SolarCity. His company expects

States with the most solar homes:

California
607,689

Arizona
126,894

Massachusetts
38,504

New Jersey
33,701

Megawatts of U.S. residential solar installed:

494 in 2012

792 in 2013

SOURCE: SOLAR ENERGY INDUSTRY ASSOCIATION

IN BRIEF

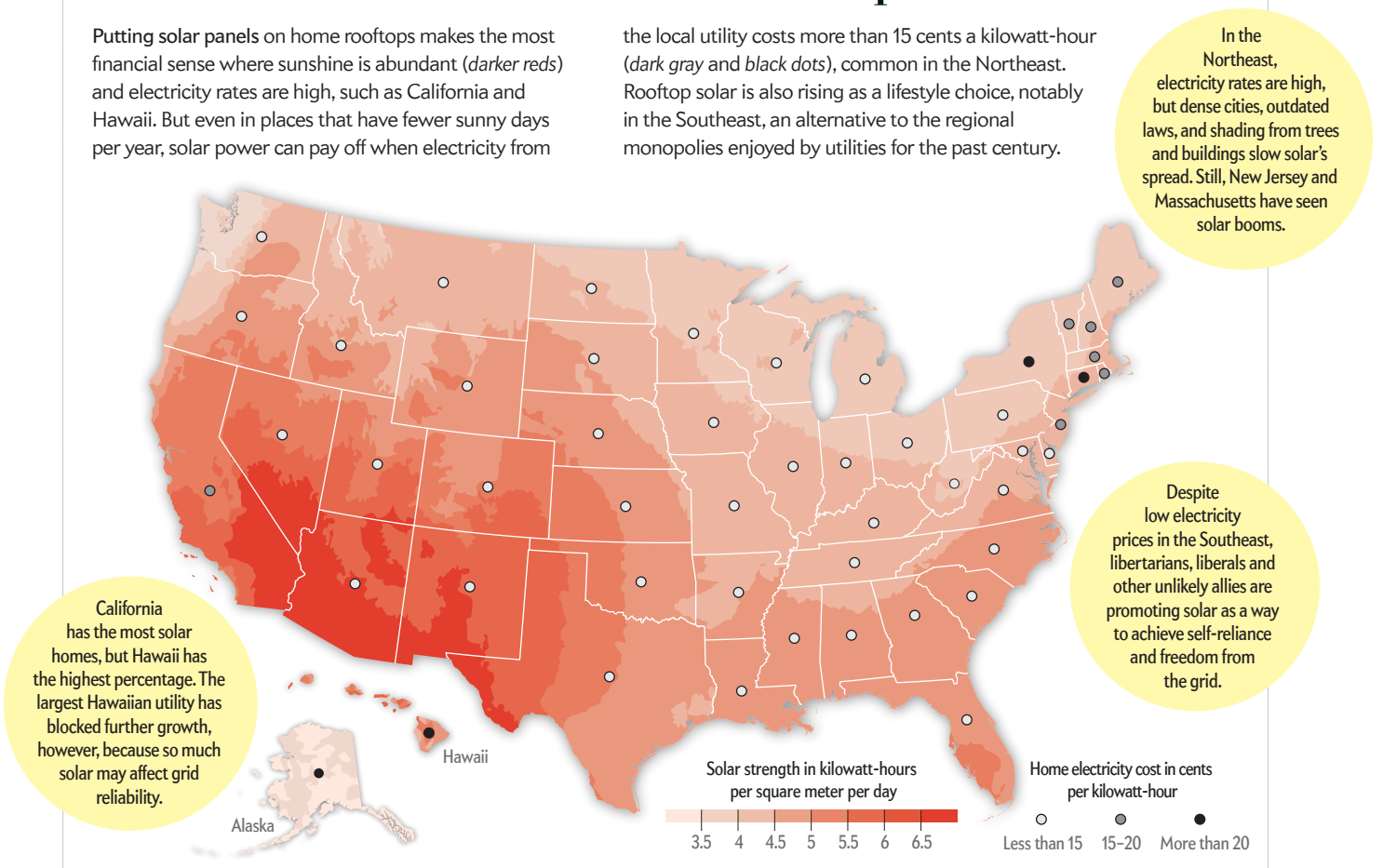
Rooftop solar power is booming, raising fears of lost revenue among electric utilities, some of which are campaigning against further growth.

The struggle is creating unusual political alliances. New policies will be needed to make sure enough funds exist to maintain a reliable electric grid.

Energy-efficient homes, paired with home-based solar, fuel cells and batteries, could make the American dream of energy independence a reality.

The Most Profitable Places for Rooftop Solar Power

Putting solar panels on home rooftops makes the most financial sense where sunshine is abundant (*darker reds*) and electricity rates are high, such as California and Hawaii. But even in places that have fewer sunny days per year, solar power can pay off when electricity from the local utility costs more than 15 cents a kilowatt-hour (*dark gray* and *black dots*), common in the Northeast. Rooftop solar is also rising as a lifestyle choice, notably in the Southeast, an alternative to the regional monopolies enjoyed by utilities for the past century.



to deploy at least 500 megawatts of rooftop solar in 2014, close to double its 2013 business. A federal tax credit for solar installation helps, allowing homeowners or their proxies to deduct up to one third of the cost of buying and installing such systems. Various state, local and utility incentives can make the deal even sweeter.

Enticements such as these have made solar power wildly popular in Arizona. More than 15 rooftop arrays are installed on homes in the state every day, according to APS. "When you go down the street, you see every other house has solar panels," Cox says. The number of these "solar independents" grew from just 4,770 in 2010 to more than 30,000 today, says Marc Romito, APS's manager of renewable energy, which includes large solar power farms and, potentially, community solar. But with homes making their own electricity, utilities lose lucrative customers and confront a dwindling base over which to spread big infrastructure costs, such as building new power plants or maintaining the grid. The cost of maintaining the local grid that supplies electricity—when solar panels do not—amounts to at least $60 per month per household, by APS's reckoning, a cost that solar homeowners avoid paying. As a result, the utility charges its nonsolar customers that extra $60 for each household that goes solar. "This shift in cost could have spiraled out of control," Romito says, forcing the company to lead the charge against the current setup for solar at home.

The issue is bigger than Arizona; more than 40 states allow property owners to sell excess energy generated by solar panels back to the grid, and most require the utilities to buy it. Although solar installations account for less than one quarter of 1 percent of U.S. electricity supply, if rooftop arrays became as ubiquitous as chimneys, the utilities fear that they could go out of business or exist merely to maintain the grid. Electric companies have not taken that big revenue hit yet, but they see it coming. As a result, utilities in Oklahoma and Wisconsin have also begun putting out propaganda against solar homeowners, and in Hawaii they have succeeded in blocking further solar system connections.

CONSUMERS PUSH BACK

SOLAR HOMEOWNERS have fought back, energized by the savings but also by energy independence. In 2013 Arizona homeowners and solar industry representatives ran their own ads touting the benefits of solar, including self-sufficiency, less pollution and increased competition for mini monopolies such as APS. And they dismissed utility fears of solar freeloaders. "We pay a bill just like everybody else," says Sue Mitchell, a Phoenix-area resident with rooftop solar who has spent 26 years educating Girl Scouts on self-reliance, among other pursuits. Her home system provides about half the power her family needs. Phoenix homeowner Scott

NATIONAL RENEWABLE ENERGY LABORATORY *www.nrel.gov/gis/solar.html (solar data)*; *ELECTRIC POWER MONTHLY*, U.S. ENERGY INFORMATION ADMINISTRATION, MAY 2014 *(electricity costs)*

Map by XNR Productions

McCay, who does not have solar, notes that after a decade of home improvements such as better insulation and more efficient lightbulbs, his electricity use fell by roughly 18 percent, but his monthly bill from APS increased by 33 percent, thanks to rate hikes.

Unlike the utilities, many homeowners also fancy the idea of a decentralized power system that is less dependent on the grid, in which homes largely supply their own energy. How these skirmishes get resolved could reshape how electricity is supplied and how climate-friendly that system will be—first in Arizona and California but then in other parts of the U.S. and the world. Solar booms in Australia, Spain and Germany are causing similar woes, including the near death of some major German power companies. Globally, more than 100 gigawatts of solar power have been installed—enough to power nearly 17 million American homes.

To influence the outcome, the utility-funded research group Edison Electric Institute released a report in January 2013 entitled "Disruptive Challenges." The report notes that home solar, which it calls "distributed energy resources," could eventually allow too many Americans to get off the grid, putting their utilities into a death spiral of fewer electricity sales to cover rising maintenance costs. That would drive up electricity prices and, as a result, encourage more people to install rooftop solar. The roughly 3,000 utilities that now control U.S. electricity could be a dim memory in a decade or two, the report suggests.

That point may be overstated. Rooftop solar would struggle to meet all of the U.S.'s electricity demand, particularly in cloudy climes or where electricity from the grid is cheap. Even in places with the most solar homes, such as California and Arizona, the impact on utilities is still small—APS, for example, simply recoups its costs from its remaining nonsolar customers. But in Hawaii, Hawaiian Electric has restricted new solar-at-home connections while it studies the impact of the solar boom on its grid, earning the utility a rebuke from state regulators for delaying tactics and a failure to deal proactively with home-based generation.

The bigger challenge for utilities—and one that solar at home and energy efficiency may exacerbate—is the slowdown in growth of electricity use nationwide since 2000. Because many, though not all, utilities make much of their profits by building new power plants, transmission lines and other grid infrastructure such as smart meters, their prevailing business model faces a transformation in the next decade or more—one that may be helped or hurt by solar power at home. New incentives and new business models, such as community solar, will need to be invented or come to the forefront to ensure a reliable electricity supply in the U.S.

The promised independence that this self-generated power would provide has brought together some unlikely allies. Georgia Power, a subsidiary of the Southern Company utility, attempted to block solar power development. That caused the local Tea Party, led by activist and grandmother Debbie Dooley, to form what she called the "Green Tea Coalition" with local environmentalists from the Natural Resources Defense Council, Sierra Club and other groups. Their goal: to encourage solar rooftops in the state. "Solar is a natural fit for conservatives," says Dooley, who professes amazement at conservatives who claim to be in favor of a free market but support a government-mandated monopoly like local utilities. "The bottom line is that energy has to compete on a level playing field," she says. "Let the consumer decide."

As a result of this unlikely alliance, the Georgia Public Services Commission—an all-Republican committee that regulates the utilities in the state—voted to require Georgia Power to include more solar in its future plans.

A schism of sorts is forming within the Republican Party, too. Libertarians and Tea Partiers like Dooley who support a homeowner's property rights have sided against other conservative groups such as Americans for Prosperity and think tanks like the Heartland Institute, both supported by oil magnates Charles Koch and David Koch. Grover Norquist of the Republican group Americans for Tax Reform has decried the Georgia Green Tea alliance and other conservative outfits that support solar at home, arguing that they have been co-opted by a solar industry that is actually a form of what Norquist calls "crony capitalism."

Still, property rights and self-reliance seem to be issues that most Americans can support. "Customers in Arizona are going solar because they now have control of their own energy," Rive notes. That outlook has led to "solar rights" laws in purple Midwestern states such as Wisconsin and Iowa. The laws prevent local municipalities, homeowner associations, or the like from prohibiting home solar—as has been the case in Arizona.

One large part of the conundrum is exactly how much a utility loses when a home goes partially off the grid, in terms of how much it must pay for the power that home sells back to the grid, a rate that is determined by state regulators. When APS launched its anti-solar salvo, the company argued that it pays too high a price for homemade electricity—the same 11 cents per kilowatt-hour it charges regular customers. The publicly traded company also says solar homeowners should be charged additional fees to pay for their share of the upkeep of power lines and other infrastructure that their homes still use. APS urged the state commission that oversees electricity to allow the charge. As in most cases related to electricity, regulators constrained the moves of both the utility and homeowners.

Not all solar proponents sided with homeowners. James Hughes, CEO of the largest solar panel maker in the world, Arizona-based First Solar, supported APS in its "cost shift" fight. On the other hand, Barry Goldwater, Jr., a former congressman who heads the group Tell Utilities Solar Won't Be Killed, argued that APS was attempting to discourage solar at home to save its revenues rather than finding ways to profit from this new reality.

Utilities might actually be underpaying solar homeowners, according to an analysis run by one of their own: Austin Energy in Texas. The municipal utility concluded that it should pay solar homeowners three cents more than the retail electricity rate, for savings in avoided transmission losses and the ability to delay building large power plants to meet otherwise rising demand,

Installed price of U.S. residential solar system per watt:

$5.09 in 2012

$4.59 in 2013

43 states allow some or all residents to sell power back to their utility company

SOURCE: SOLAR ENERGY INDUSTRY ASSOCIATION

SCIENTIFIC AMERICAN ONLINE To learn more about solar growing pains, visit ScientificAmerican.com/nov2014/solar-at-home

which can require multibillion-dollar investments. Those factors translate into electric bill savings for even nonsolar homeowners. A similar analysis for the Nevada Public Utilities Commission found that solar homeowners in that state were not raising costs for their neighbors.

But APS argues that solar at home saves only on fuel costs, not deferred or reduced maintenance of the grid. "Because of the intermittent nature, solar does not reduce transmission and distribution costs at all," Romito says, noting that this is based on real experience in Flagstaff and Phoenix, not just studies conducted on paper.

Thus far the regulator that governs Arizona utilities, the Arizona Corporation Commission (ACC), seems to agree—in a small way. It decided in November 2013 to impose a charge on solar homeowners of 70 cents per kilowatt of installed solar, or an average of $5 per month. That charge is almost enough to eliminate the financial benefits of leasing solar arrays. "It's hard to make things work in Arizona now," Rive says, although APS has seen no decline in homes looking to connect new solar systems.

Solar proponents vow to keep fighting. "We didn't do enough to uncover the true effects, both positive and negative, of distributed rooftop solar," argues Dillon Holmes of Clean Power Arizona, an advocacy organization for renewable energy in the state.

And APS expects to continue the fight at the commission in 2015, when it will make a decision on new electricity rates. "We applaud the ACC for cutting through the rhetoric and focusing on how the cost shift impacts nonsolar customers," said CEO Don Brandt in a statement on the ruling. But the current policy "falls well short of protecting the interests of the one million residential customers who do not have solar panels."

The same sentiment is rising across the U.S. and abroad, even in those nations that are solar energy leaders. Germany and Spain are considering fees on solar power for access to the grid to ensure maintenance of this critical infrastructure.

BACKUP PLAN

SUCH CHARGES COULD SLOW solar's growth, which is why the outcome in Arizona could have national and even international implications—for the solar power industry and for climate change. Solar panels on rooftops result in far less global warming pollution than electricity from burning coal and use less water compared with the cooling needs of a nuclear power plant.

Solar power may prove a strong force, even if federal tax credits end for good in 2016, when they are slated to expire. If module prices drop to 50 cents per watt, then solar power will become as cheap as other sources of electricity in all 50 states. SolarCity is building a new factory in Buffalo, N.Y., to churn out one gigawatt of solar panels a year—volume manufacturing that could help bring cost down. The U.S. Department of Energy has invested $87 million in projects that could reduce the cost of a solar module and its installation to 50 cents per watt each. And a survey by the National Association of Home Builders found that more than half of home construction firms plan to offer houses with solar panels by 2016. The Edison Electric Institute projects that solar at home could be cheaper than the grid in as much as one third of the U.S. by 2017.

Some solar homeowners want to distance themselves even further from their utilities. "I'm looking to get batteries and go completely off the grid," says Jerry Dieterich, a Phoenix general contractor who leases a 6.4-kilowatt system for his roof. Solar panel manufacturer SunPower has partnered with KB Home to offer rooftop systems with battery storage in 150 California communities. SolarCity serves more than 100 different homebuilders and has partnered with electric automaker Tesla to provide a solar and battery package. And a Rocky Mountain Institute analysis suggests that solar systems paired with batteries could compete on cost with the grid by the 2020s.

In the end, this spread of solar could transform not only the American electric utility but also make the bucolic lifestyle of the suburbs sustainable in a novel way. Solar at home—perhaps paired with an electric car in the garage or a battery bank in the basement to store electricity generated from sunshine for use at night or on a cloudy day—could reduce the profits of the companies that operate the grid, although the grid is unlikely to disappear. A fuel cell or small generator running on natural gas could also facilitate the switchover. "This is not just a solar conversation," APS's Romito notes. Future electricity regulation "needs to consider every available technology, whether fuel cells, or battery storage, or the next thing that's going to come on a changing system."

In other words, renewable power at home is about freedom, which is why the solar war is realigning local and maybe national politics. "How shockingly stupid is it to build a 21st-century electricity system based on a system of 130 million wooden poles?" asked NRG's Crane at a summit in February. Within a generation, he said, the grid could be "an antiquated backup system."

Given that prospect, utilities are doing "everything they possibly can before solar becomes too big for them to stop," Rive says. Instead, he and others argue, utilities should embrace solar and even try to lead to avoid becoming low-revenue grid tenders.

That utility transformation has begun. "We recognize that our customers really want to have rooftop solar," Romito says. To provide a new option, APS has proposed a plan to install and maintain solar power on 3,000 homeowners' roofs in exchange for a $30 credit per month to each household for 20 years.

Similarly, rules can be changed to enable utilities to make money from cutting electricity use. Already many people and businesses have made improvements that reduce consumption, such as tightening up ducts, replacing leaky doors and windows, installing Energy Star appliances and adding insulation. "I tell people that the thing to do is to get your house tight, get it energy-efficient first," Dieterich explains. Then install solar for control over power production. As Dieterich says about his own rooftop solar: "It has done nothing but made me money." SA

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FROM OUR ARCHIVES

A Solar Grand Plan. Ken Zweibel, James Mason and Vasilis Fthenakis; January 2008.

scientificamerican.com/magazine/sa

TERMITES BUILT this cathedral-shaped mound in Litchfield National Park in Australia. Made from soil, saliva and dung, such structures can stand more than 18 feet high.

LIFE SCIENCE

the evolution of architecture

The homes that animals build are just as much a product of evolution as the creatures themselves

By Rob Dunn

IN BRIEF

Birds, mammals, fish, social insects and many other animals construct a wide variety of intricate nests and homes. Researchers have long known that genes and behaviors must have evolved to enable creatures to build these structures. **Only in recent decades** have scientists started to reveal the genetics of animal architecture, the physics that holds their creations together and the surprisingly simple behavioral rules that allow many small-brained critters to build empires. **One day we may be able** to create computer programs that follow the same architectural rules as social insects to design more efficient cities.

Rob Dunn is a biologist at North Carolina State University and a writer whose articles have appeared in *Natural History*, *Smithsonian* and *National Geographic*, among other publications.

I HAVE LONG BEEN FASCINATED BY THE HOMES THAT ANIMALS CONSTRUCT. Over the years I have contemplated the nests of hundreds of different species—including ants, termites, wasps, birds, fish and mice—by poking and prodding nests in the wild, manipulating them in the laboratory and reviewing the work of other scientists. I have dug holes meters deep, trying to find the bottoms of ant nests. I have snorkeled over bluegill fish, watching them excavate and tend to their dish-shaped nests. As a boy, I even tried to swim up into a beaver lodge.

In studying these homes, I have encountered an astonishing diversity of forms. Some nests are long, straight tunnels. Some are branching labyrinths. Others spin in wild helices or take on elaborate fractal forms. But what I find most remarkable about each construction is that it evolved. Each type of nest is just as integral a part of the species and individuals that made it as the animals' limbs, eye color, skin covering and genes. Indeed, the instructions to build nests must be, at least in part, inscribed in the genes of the animal kingdom's architects.

Only now are biologists finally beginning to understand how such architecture evolved. Recent research has started to pinpoint some of the genes responsible for nest-building behavior, reveal the physics underlying the shapes of different animals' nests and even explain the way that some puny-brained critters work together to construct entire metropolises. Like many good stories, this one begins in a garage.

A HOUSE FOR A MOUSE

IN 2003 HOPI E. HOEKSTRA was a young scientist, then at the University of California, San Diego, trying to uncover the links between genes and the behavior of mice. She already knew that different kinds of mice build differently shaped tunnels. Jesse N. Weber, then a student in Hoekstra's lab, began to wonder if he and Hoekstra could find the genes associated with building one type of nest rather than another.

Weber's first task was to craft indoor enclosures that were large enough and held enough dirt to entice mice to dig tunnels. He improvised, building cages out of plywood, nails, playground sand, and other inexpensive and easily accessible materials. Because no lab space was available for the project, he built the cages in the garage attached to Hoekstra's home. The results were ugly but effective: a series of sheds held together by duct tape and ambition.

Hoekstra was already studying field mice in the genus *Peromyscus,* so Weber decided to fill these cages with two *Peromyscus* species: oldfield mice (*P. polionotus*) and deer mice (*P. maniculatus*). Deer mice, which live across much of North America (except the far Southeast), dig a single, short tunnel, whereas oldfield mice, which live exclusively in the far Southeast, dig a long tunnel with a branching escape route that dead-ends just below the soil surface.

When scientists studying lab mice want to find the gene behind a particular trait, they often mate mice that do have that trait with those that do not and see which of those parents the offspring resemble. If the new generation has the trait, it might just be encoded by a dominant version of a single gene, a bossy allele. This trick—the same one Gregor Mendel used on his pea plants—works best for relatively simple relations between genes and traits. Tunnel building did not seem likely to be a simple trait encoded by one gene, but Weber gave the approach a try, anyway. Oldfield and deer mice do not mate in the wild, but, as they say, what happens in the garage stays in the garage. Weber got the mice to mate; he then allowed the resulting progeny to dig.

The most probable scenario was that the tunnels of the hybrid mice would be a complex amalgam of those built by their parents, the middling mélange of genetic complexity. Instead this first generation of hybrid mice all built long tunnels with escape hatches. In theory, this pattern could result from simple dominance involving as few as two genes: one associated with tunnel length and the other with the escape hatch. Inheritance of one or two dominant versions of the tunneling gene from an animal's parents would yield long tunnels; likewise for the

NO PLACE LIKE HOME: A common wasp nest is in early stages of construction (*upper left*); green tree ants use silk to stitch leaves into a home (*lower left*); weaverbirds construct their dwellings from materials such as grass and palm leaves (*below*).

INGO ARNDT *Nature Picture Library (page 72 and wasp nest);* INGO ARNDT *Minden Pictures (ants and birds)*

hatch gene. Only two recessive versions of either gene would result in truncated tubes or no escape hatch. But Weber and Hoekstra thought such simplicity unlikely.

Yet when they crossed the hybrid mice with the oldfield mice (a backcross), they were surprised to find something akin to what might be expected from simple dominance, at least for escape tunnels. About half the progeny built escape routes, and half did not. Tunnel length, in contrast, varied continuously, suggesting more complexity. In follow-up work, Weber, now a postdoctoral fellow at the University of Texas at Austin, and Hoekstra, now a professor at Harvard University, ultimately identified the particular regions of the mouse genome associated with each attribute. Escape-hatch building is controlled by a group of genes, or even just one gene, on a single chromosome. Tunnel length appears to be governed by several genes scattered among three parts of the genome, which would explain the greater complexity observed in Weber's crosses.

Weber and Hoekstra's work demonstrated that even in smart animals, such as mice, complex behaviors involved in nest construction can be both genetically encoded and a product of evolutionary forces. With this discovery, Weber and Hoekstra pulled a string loose from an enormous ball of yarn. To unravel the rest of the ball, Weber, Hoekstra and other scientists will have to repeat similar experiments for each of the tens of thousands of species that build. Scientists in Russell Fernald's lab at Stanford University are already exploring the genes underlying nest design in cichlid fish in which some species make divot nests and others make mounds. More studies will follow.

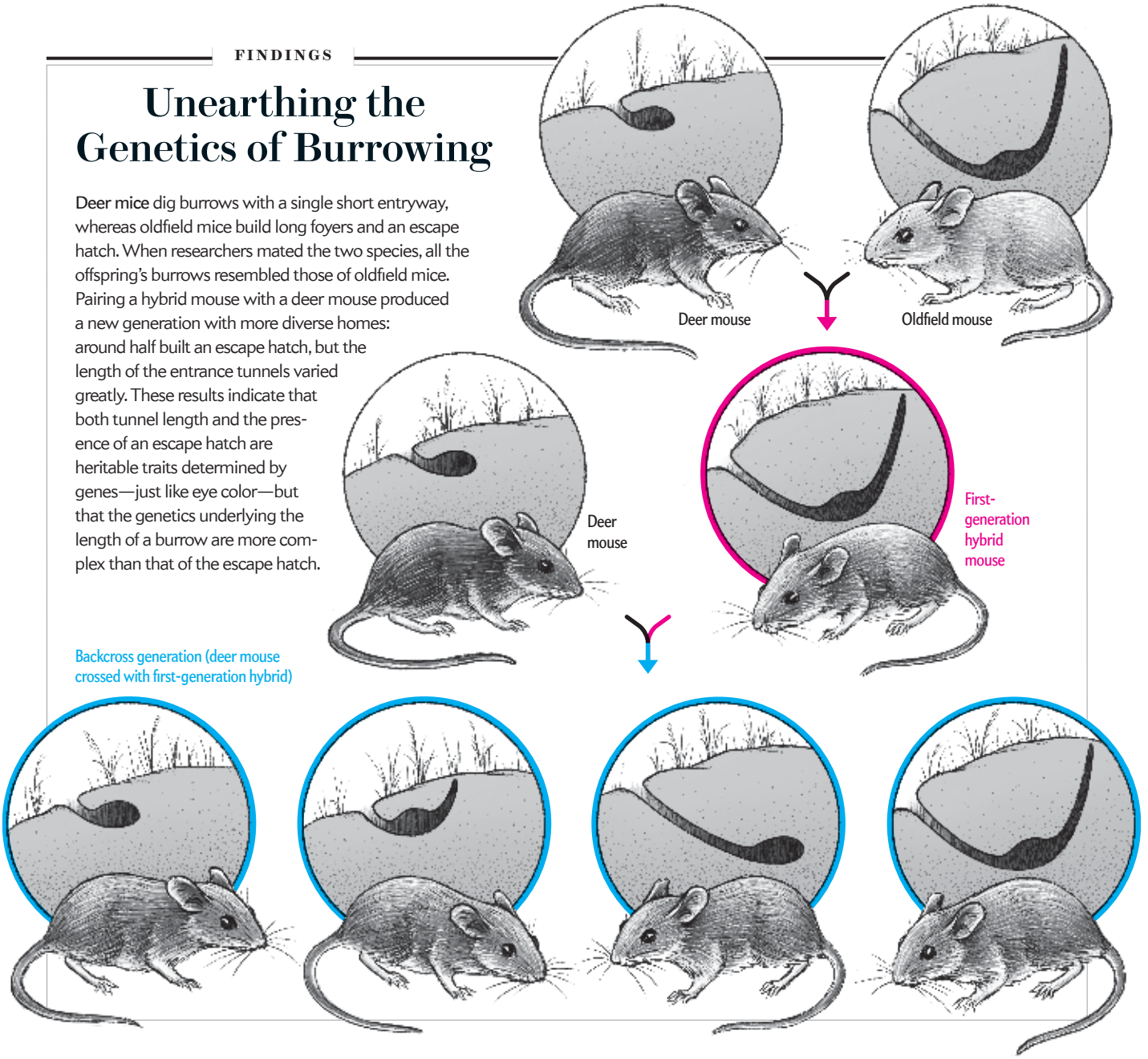
The genetics of building in some animals will no doubt prove more complex than in field mice. Some species, such as canaries, learn how to build—or, in the case of bowerbirds, decorate—their constructions by mimicking their parents and peers. Others, such as many social insects, are difficult to breed properly in the lab. But the genetic basis of building is not the only, or even the deepest, mystery surrounding the animal kingdom's architects. There is also the issue of why nests vary so greatly across different species and how to explain their particular and often peculiar shapes.

TOWERING TERMITES

THE NESTS OF *PEROMYSCUS* MICE and most mammals are fairly simple; they do not vary immensely from region to region and species to species—an extra tunnel here, a larger chamber there. Even among birds, real variety in nest structure is the exception rather than the rule. Most bird nests are simple cups, bowls or pouches, differing in the subtleties of their shape and components rather than in more fundamental ways. The true animal masters of architecture are social insects. The beehive, the wasp

Unearthing the Genetics of Burrowing

Deer mice dig burrows with a single short entryway, whereas oldfield mice build long foyers and an escape hatch. When researchers mated the two species, all the offspring's burrows resembled those of oldfield mice. Pairing a hybrid mouse with a deer mouse produced a new generation with more diverse homes: around half built an escape hatch, but the length of the entrance tunnels varied greatly. These results indicate that both tunnel length and the presence of an escape hatch are heritable traits determined by genes—just like eye color—but that the genetics underlying the length of a burrow are more complex than that of the escape hatch.



nest, the ant mound, the termite hill: each of these varies from one species to the next more than the bodies of the insects themselves do. Termite workers nearly always look the same—flaccid abdomens connected to round heads and mandibles—but their nests can look like Rorschach forms, skyscrapers eight meters tall, domes, pyramids and even crumbly balls suspended in trees.

It would be easy to discount this diversity as accidental—the manifestation of a clumsy collective of unknowing beasts. Yet in many cases that have been studied, the features of nests are consistent from one structure to the next within a species. This consistency extends to parts of the nest that appear to have no function, such as vacant chambers. But termites build these puzzling features into their nests over and over again. In recent years scientists have started to uncover the purpose of such chambers.

This architectural puzzle is especially apparent in the nests of *Macrotermes bellicosus* termites, which farm and harvest *Termitomyces* fungi inside their homes. Surrounding these gardens and their millions of attending termites are central towers with pointy, sealed tops. Around these towers sit well-used chambers in which workers, and even the queen, live, along with an outer row of unused chambers. The creatures coat the unused chambers with a hard but porous surface that allows air, but not predators, to pass through.

Judith Korb of the University of Regensburg in Germany has been particularly interested in these features of giant *Macrotermes* mounds. With help from temperature sensors, collaborators and a whole lot of digging, Korb has discovered that the seemingly unusual architectural features of termite nests work like a giant mud lung. During the day the heated air, full of carbon dioxide exhaled by the termites, rises into the center of the nest. There, in the thinnest part of the mound, the hot air and CO_2 diffuse upward. If they did not, the insects would suffocate in their own exhalation. As night comes, cooler, oxygen-rich air diffuses back into the bottom of the nest, in through the empty

SCIENTIFIC AMERICAN ONLINE To view a slide show of varied nests, visit ScientificAmerican.com/nov2014/nests

Illustration by Jillian Walters

outer chambers. As it does, it pushes CO_2-laden air out. This big mud lung is adapted to the climate in which the *Macrotermes* termites live. Far from being accidental and useless, the nest's empty chambers allow the termite collective to breathe.

In addition to microclimate control, nests also shield their builders from enemies. Termite nests are as thick as they are because of the threats posed by aardvarks, anteaters, armadillos, echidnas and a small army of other organisms that specialize in eating termites. To protect its young from parasites, a newly identified species known as the bone-house wasp blockades its nest with pungent piles of fearsome ant corpses. Then, of course, there is the option of an escape tunnel. The oldfield mouse lives in the southeastern U.S., where snakes are abundant and diverse. Its escape hatch most likely is an adaptation in response to such serpents. Some tropical ants have recently been shown to keep a pebble near their nest entrance. When army ants approach, they close the nest with their pebble. Other ants defend against army ants by having soldiers with heads just wide enough to plug the entrance. Some birds defend their nests through camouflage, creating inconspicuous nests, such as those of cream-colored coursers, which look like little more than pebbles in the desert sand.

Perhaps the greatest challenge for nature's builders is one that scientists have only begun to consider: excluding deadly organisms too small to see, such as bacteria and microscopic fungi. In the past few years researchers have discovered that some termites build their nests out of their own feces, often mixed with other materials. In these fecal bricks, some termites plant a garden of *Actinobacteria,* which helps to battle deadly fungi by producing antifungal compounds. Leafcutter ants cultivate similarly defensive bacteria on their bodies.

COMMUNAL CONSTRUCTION

ONCE WE UNDERSTAND the environmental conditions and threats that have favored a particular nest type and the genes associated with that type, we will still need to figure out how those genes guide an animal through the nest-building process. In the case of social insects, it is tempting to think that the colony merely obeys a ruler—some fat-bodied queen with a scheme. But there is no master plan, just the unconscious actions of many individuals following simple rules that, when acted out in concert, can produce the enormous nests of termites, the cavernous lairs of ants and even the intricate honeycombs of bees.

Over the past 15 years scientists have developed increasingly sophisticated mathematical models that mimic how such simple rules culminate in the construction of termite homes. The models assume that the building blocks the termites use have a pheromone in them that triggers additional building but eventually wears off. One worker puts down a block, and another, tempted by the first block's odor, follows suit. The process continues until two curving walls come together to form a roof. The act of building walls and roofs was easy to simulate. But what about the precise arrangement of those walls to form tunnels and rooms?

Here, too, simple rules seem to be at the heart of the complexity, although the story continues to emerge. Regarding, for example, the royal chamber—the oval room that surrounds the queen termite—it appears that the queen emits a pheromone that prevents workers from building walls close around her. The workers, as a result, build a wall a consistent distance from the queen. Rather than imagining they have discovered exactly how these termites and wasps build their homes, scientists believe they have gleaned the minimum number of rules necessary to produce something as sophisticated as a nest. The answer is very few—a handful encoded in the insects' genes and tiny brains.

In contrast to the diverse, genetically encoded, often cooperatively constructed nests of rodents and social insects, the nests of wild primates are humble. Chimpanzees and gorillas break off leaves to make beds; one of my colleagues has slept in these beds and describes them as "comfortable" but only relative to their absence. Our ancestors are unlikely to have been very different until, at some point, our kind began to build in earnest. Using language to coordinate their efforts, our ancestors built homes out of what was at hand: sticks, mud, grass and leaves. No genes encoded the precise designs of these shelters. Look at images of indigenous houses around the world, and you will see that, to a large extent, form follows function and necessity. In cold regions, walls are made thicker. In warm regions, walls are not built at all. You will see traditional houses that mimic termite nests, ant tunnels and even, in the cold, the sod thatch of bumblebees.

The more time we invested in considering how to build houses, the more roles houses took on: they have become status symbols, artworks and even markers of culture. Houses in some new Arizona subdivisions now look very similar to those in New York subdivisions because we are conditioned by society to desire the same "good life"—the same house and white picket fence—regardless of where we live, regardless of climate, predators, pathogens or anything else. We have disconnected our architecture from some of the imperatives of the wild.

Recently, though, a different approach to architecture has emerged, a counterbalance to the trend of individually designing each room, each support, each door and garden. The designs of animals, as we now know, emerge from genes that encode simple rules. If termites can use simple rules to produce empires, we, too, might do the same. Some architects are now trying. Scaling up the simple rules used by social insects to human-sized cities requires tremendous computing power, but such power is increasingly a reality. The final challenge is knowing which simple decisions to mimic—in what situations it is best to behave like a termite, an ant or a bee. We are as close to the answers as we have ever been. Yet to watch empires of mud and spit rise out of the ground one mouthful at a time is to realize that the earth's most ancient architectural techniques remain very much a secret. SA

MORE TO EXPLORE

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START YOUR ENGINES: Todd Reichert sits at *Atlas*'s controls while Cameron Robertson adjusts cables.

David Noonan is a freelance science writer and former *Newsweek* senior editor.

AERONAUTICS

impossible flight

A human-powered helicopter could not fly, experts concluded. Then two young engineers proved them wrong and won a quarter of a million dollars in the process

By David Noonan

IN BRIEF

For more than 30 years aeronautical designers failed to get a human-powered helicopter to hover in place for a minute, defeated by the vexing challenges of vertical flight and limited power. The AHS Sikorsky Prize, offered to inspire engineers, went unclaimed. **Two Toronto engineers,** Todd Reichert and Cameron Robertson, went with giant rotors to make up for limited power, questioned every assumption about helicopter design and last year flew away with the award. **Built with easy-to-find** material and by a small team, the successful craft shows that advanced innovation is not just the province of large, high-tech companies.

REED YOUNG

When they set out in 2011 to build a human-powered helicopter that could fly 10 feet into the air and hover in one place for 60 seconds, Todd Reichert and Cameron Robertson faced one major obstacle: it was supposed to be impossible.

Experts had reached that conclusion after 30 years of failure and crashes, beginning in 1980, when the American Helicopter Society (now AHS International) offered a prize, eventually worth $250,000, for a successful human-powered flight. All evidence suggested that a single pilot simply could not generate enough power to fly that high and for that long. Aeronautical engineer Antonio Filippone of the University of Manchester in England ran through the numbers in a 2007 paper in the *Journal of the American Helicopter Society* and reported that the idea—and any aircraft based on it—just would not fly: "Overall, all the requirements … of the American Helicopter Society cannot … realistically be achieved."

Reichert, 32, and Robertson, 27, only learned about Filippone's paper after they won the money and the award, known as the AHS Sikorsky Prize, with a record-setting flight in June 2013 by their giant, four-rotor, bicycle-powered machine called *Atlas*.

Like an awesome toy built with Paul Bunyan's Erector set, *Atlas* features four skeletal beams, constructed from carbon-fiber tubing and cables made from high-tech line fibers and assembled into an enormous, arching X with a diagonal span of 88 feet. The four rotors, each 67 feet in diameter, with balsa wood ribs and see-through Mylar skin, sit at the end of each arm of the X. Dangling on lines from its center, which arches 12 feet above the ground, is a modified racing bicycle on which Reichert, *Atlas*'s human engine, supplies the pedal power that turns the rotors via an intricate system of spools and lines. That energy lifts the 121-pound craft off the ground.

Their 64-second flight, after so many before them had failed, demonstrates that in an era dominated by large teams of engineers working for huge companies such as Lockheed Martin and Northrop Grumman, a small, nimble group can solve the hardest problems. Benjamin Hein, a senior engineer at Sikorsky Aircraft and chair of the Sikorsky Prize committee in 2013, says the young designers had to figure out the ideal size and weight of an aircraft with a very limited power source, an optimal rotor design and a workable flight-control system. He notes there are important lessons for industry here, chief among them Reichert and Robertson's willingness to fail and make major design changes quickly. "That's the thing that big companies can't do," Hein says.

In another demonstration of the power of the few, the laptop computer program that Reichert and Robertson wrote to optimize their design is now part of a NASA software tool kit used to configure vehicles intended to fly much farther than *Atlas*. Next year the two engineers plan to use it themselves to design a human-powered plane to compete for the Kremer Marathon prize, which will go to the first craft to complete a 26-mile course in less than one hour. (The current speed record is 27.5 miles per hour, set during a flight that lasted just over two minutes.)

It is hard to resist invoking another pair of independent tinkerers, Orville and Wilbur Wright, when writing about Reichert and Robertson. Like the Wright brothers, the two men—who met as engineering students at the University of Toronto and now run AeroVelo, their "design and innovation lab"—share a passion for manned flight. Reichert says that they want "to inspire people to see how much more we can do if we really prioritize efficiency." That is why they mostly use materials that have been around for decades, such as balsa, Styrofoam and Mylar, and why they embrace the limitations of working with human power. It means they cannot go and buy a better engine, Robertson says. "You have to solve your problems without changing your power supply. You can't just increase it." And surely bicycle shop owners Wilbur and Orville would appreciate the central role of the bicycle in Reichert and Robertson's inventions. In addition to *Atlas,* the two built a successful bicycle-powered flapping-wing aircraft called an ornithopter.

But the most Wright-like thing about Reichert and Robertson is their method. "The Wright brothers were mechanically inclined," Reichert says. "They knew how to tweak things and fix things, but they were also scientifically rigorous, which is really the combination that you need."

The two Canadian engineers are not helicopter designers, which is why they were ignorant of the scientific papers dooming them to futility. What they did know, however, was that the complex computations they had to do would potentially require hours and hours of expensive supercomputer time that they could not afford. And the duo felt their software needed to improve on the conventional approach to aeronautic design, in

UP AND AWAY: ***Atlas*** **takes off for its prizewinning flight in 2013, its four rotors carving the air in an indoor soccer stadium. Reichert, suspended below the blades and pedaling hard, kept the craft aloft and stable for just over one minute.**

COURTESY OF MARTIN TURNER *Visibiz.com*

which the structural and aerodynamic components are developed by separate teams and handed back and forth. That process, Robertson says, results in "a solution that is not perfect from the aerodynamic side and not perfect from the structural side."

To address all these issues, what they needed was a program that would simultaneously merge the structural and aerodynamic elements of design parameters that were specific to human-powered helicopters. It also had to be cheap to run. And fast.

So they created one on their laptops in a five-month code-writing marathon that in part drew on earlier work Reichert had done for the ornithopter, which had earned him his Ph.D. To get from an unaffordable supercomputer to a laptop, they decided to forgo high-fidelity modeling capacity in favor of medium-fidelity models of things such as airflow around the rotors. High-fidelity code can provide precise details about what is going on where the aerodynamics are very complex, like at the tip of the rotor. But although that standard is necessary for commercial aircraft design, it was not required for the low, slow, readily modified *Atlas*. "Medium fidelity will always allow you to get within, say, 2 percent of the correct answer," Robertson says, "and that's really what we were looking for."

Their custom program enabled them to test almost any given helicopter design on their laptops. They just plugged in the dozens of variables for a proposed design, such as rotor geometry and the weight, dimensions and failure modes of the construction materials, such as carbon-fiber tubes. The program crunched all those data and, in a matter of minutes, spit out the optimal version of the given aircraft and the minimum amount of power needed to get it airborne. The code is now being used in NASA's software library because the agency liked the way it got very close to the correct answer very quickly.

The first design decision Reichert and Robertson made was to go big: long arms and big rotor blades to maximize lift. Watching the video of *Atlas*'s winning flight, its rotors, turning at just 10 revolutions per minute, may seem too slow to be effective. But it is their huge size, not their speed, which supplies the lift that gets the machine off the ground. The previous failures, the two felt, artificially limited the size of helicopters and rotors to make them fit in places like gymnasiums because wind gusts outdoors would be too much for these delicate aircraft to handle. Staying inside was smart, the engineers agreed, but gyms were too small. That is how a cavernous old barn north of Toronto—and then the Soccer Center near the same city—became the Kitty Hawk of human-powered helicopter flight.

The other major design constraint for *Atlas* was the weight and power capacity of its engine—Reichert, a shade over five feet, 10 inches, and weighing in at 180 pounds. The aircraft's design, however, limited the pilot's weight to 165 pounds, which meant Reichert would have to drop 15 pounds. He would also have to generate enough power during the flight to raise him-

self and the 121-pound aircraft—a total of 286 pounds—to the required height of 10 feet and remain aloft for the required time of one minute. The estimated power targets, a function of the total weight of the aircraft and the size of the four rotors, were an initial burst of about 1,000 watts to get up, followed by a steady output of around 600 watts for the remainder of the flight. Basically, it was to be a 100-meter sprint, followed by a slightly slower 400-meter sprint.

Arguably the fittest aeronautical engineer in North America, Reichert is a dedicated athlete who has competed at Canada's highest levels as a speed skater. As part of a machine, Reichert was subject to his own and Robertson's obsession with measurement. "As soon as you can measure something," Reichert says, "you can improve it." During his months-long training regimen, he and Robertson used two ergometer systems to measure his power output. Reichert helped the cause when he came in at 160, five pounds below the target weight, reducing the amount of energy required to fly the helicopter with no significant loss of engine power.

To ensure top performance, elite athletes usually time their training so they reach peak levels of fitness just before they compete. Repeated technical delays, however, forced Reichert to maintain his peak level of strength and fitness for more than nine months. Incredibly, during the winning flight, he actually exceeded the targets, generating 1,100 watts (nearly 1.5 horsepower) during the first 12 seconds before dropping back to average 690 watts for *Atlas*'s entire 64 seconds of air time.

Reichert, Robertson and their team of eight students at the University of Toronto built *Atlas* in the summer of 2012. Although they were constructing a fantastic machine to achieve an "impossible" goal, Reichert and Robertson did not waste time or money on unnecessary efforts or exotic materials. Whenever possible, they went with existing solutions, using proved "plug and play" elements to keep costs down and free them up to focus on the stickier problems. Instead of fabricating a custom, superlight bike, for example, they modified a stock Cervélo R5ca, one of the lightest production road bicycles available. As Robertson likes to tell the high school groups he sometimes speaks to, most of the materials used to build *Atlas* are available at craft and

hobby shops such as Michaels. The newest product they used was Vectran, a liquid-crystal polymer fiber for a high-tech line with exceptional strength and zero creep—once it is loaded, it does not stretch.

In the barn north of Toronto, Reichert says, the complex math and cool algorithms gave way to intuition and to trial and error. One early victim of the process was *Atlas*'s control system, a complicated arrangement of levers and wires connected to small L-shaped airfoils (called canards) on the tips of the rotors. It was supposed to prevent the helicopter from drifting outside the 10-meter-square (33-feet-square) box stipulated by the Sikorsky Prize rules by changing the pitch of the rotors.

But with too much lag time between pilot action and result, the fancy control system simply did not work. "It was really cool mechanically," Robertson says, but it could not counter drift. So they replaced it with a simpler system, rerouting a few cables to connect the bottom of the bike to the axles of the four rotors. The pilot controlled drift by leaning forward to move forward, left to move left, and so on. "I still can't believe it worked," says Reichert, who can be seen leaning hard right most of the time in a video of the winning flight. Not only did it make *Atlas* easier to

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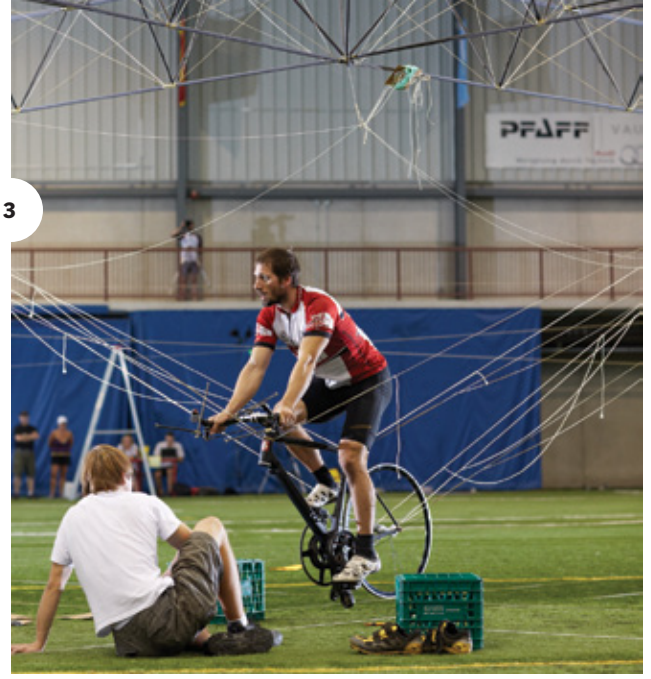
SCIENTIFIC AMERICAN ONLINE Watch the winning *Atlas* helicopter flight at ScientificAmerican.com/nov2014/atlas-helicopter



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HOW *ATLAS* WORKS: The entire craft, on the ground, looks like an X with a rotor at the end of each corner (*1*). The rotor blades, with light Mylar skins, provide lift (*2*). Reichert pedals a bicycle whose gears turn cables that spin the blades (*3*). Underneath each rotor, hubs of yellow Kevlar and carbon fiber act as spools for the cables (*4*).

fly, it reduced the total weight of the aircraft by 10 percent. Combined with a reduction in drag, this lowered the power requirement by a whopping 20 percent.

Parts of the fragile aircraft broke all the time during testing, including two spectacular crashes just a few weeks before the successful flight. Both were the result of an aerodynamic phenomenon called a vortex ring state, in which the turning rotors dip into air they have already pushed down and lose lift. The two engineers took a close look at the rotors and saw the leading edges were not smooth enough: the Mylar skin, applied in a rush as they raced to finish the aircraft, had rough spots, creating excess drag. So the duo carefully smoothed out the skin. They also shortened the carbon-fiber struts and stiffened the wire bracing system on the rotor arms.

The fixes worked. Eight weeks after the second crash, they won the Sikorsky Prize. The video showing that flight, in which Reichert appears to be flying some kind of crazy sideways construction crane outfitted with huge propellers, has been viewed more than 3.1 million times on YouTube. The competition was intended to inspire the next generation of engineers and capture the public imagination, and by YouTube measures, the *Atlas* flight succeeded.

After Reichert's winning flight, every member of the team got a chance to fly *Atlas,* each lifting off at least a foot or two from the ground. "Before that day," Robertson says, "more people had walked on the surface of the moon than had flown a human-powered helicopter. We doubled that number."

When Reichert talks about the reasons for his and Robertson's success, he goes beyond technology. He talks about their commitment to doing the impossible or at least trying to. "You have to set crazy goals," he says, "because that's what motivates people."

There is plenty of uninspired goal setting to go around, Robertson complains. Fuel-efficiency standards are his prime example. He says admirable government efforts to increase overall automobile fleet fuel efficiency, such as the current U.S. goal of 54.5 miles per gallon by 2025, an 88 percent boost over current standards, are not ambitious enough. "But if all of a sudden the government mandated a 1,000 percent increase in fuel economy," he says, "then you've forced everyone to stop and think totally differently about the problem." And that, he argues, could help launch a new era in superefficient transportation.

It is also a complete nonstarter in political and policy circles, for obvious reasons. Reichert and Robertson know that. What they hope such lofty goals will do is foster a new way of looking at seemingly intractable problems. "Taking on the impossible is not necessarily easier," Reichert says, "but it's more satisfying, it's more motivating and, in the end, it's more important."

This fall the men tried to break the cycling world speed record of 83.127 miles per hour in competition at Battle Mountain, Nev., and failed by about four and a half miles per hour. Next year they will return to the air to pursue yet another human-powered challenge that has gone unmet for decades—the Kremer prize, which carries a £50,000 award for a flight that covers 26.2 miles in one hour or less. They are already identifying constraints and assumptions and are confident they can rack up another unlikely win.

Because the only human-powered aircraft to reach that speed came down after about two minutes, well before it covered a marathon distance, one might conclude that the requirements for the prize "cannot realistically be reached." One might also conclude, correctly, this is exactly what Reichert and Robertson want to hear. SA

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Speaker: Harold Tobin, Ph.D.

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Speaker: Bill McGuire, Ph.D.

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How long can the human race survive? A major asteroid impact wiped out more than half of all life 65 million years ago, while a volcanic super-eruption 74,000 years ago may have brought our species to the brink of extinction. Learn about the prospects for similar threats in the future, along with giant tsunamis, megaquakes, and climatic mayhem.

The Biggest Bangs Since the Big One

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An astonishing transformation over the last 20,000 years has seen our planet flip from a frigid wasteland into the temperate world. Now there are signs that human-induced climate change is causing another turnaround. Could we bequeath to future generations not only a far hotter world, but also a more geologically fractious one?

Surviving Armageddon: Solutions For a Threatened Planet

Our world is constantly under threat, both from geological processes and from the cosmic forces that rage beyond our atmosphere. Can we use our scientific understanding and our technology to make the world a safer place? We'll discuss volcano monitoring, earthquake prediction, asteroid spotting and other efforts underway.

Architecture & Engineering

Speaker: Stephen J. Ressler, P.E., Ph.D.

A Field Guide to Great Structures

Many of the world's greatest works of architecture have been profoundly influenced by the principles of engineering mechanics that underlie their design. Learn how to see, analyze, and understand the many fascinating structures we will encounter during our cruise, from the Hallgrímskirkj in Reykjavik to the great bridges of the Norwegian fjords.

The Norwegian Stave Church

The stave church is a medieval building that was once common throughout northwestern Europe. Today the few surviving examples are found almost exclusively in Norway. Learn to see the stave church not just as an iconic architectural form, but as a sophisticated technological system as well.

Saint Paul's Cathedral: Evolution of the First Modern Dome

Learn about the development of the dome as a structural and architectural element from the Classical Era through the 18th century. We'll focus on the extraordinary structural innovations devised by Sir Christopher Wren for the dome of Saint Paul's, and we'll see how these innovations overcame the inherent structural limitations of earlier domes.

A Structural Retrospective

We'll examine interesting structures photographed by Bright Horizons participants during our trip, analyzing the structural system, discerning the underlying engineering principles, and assessing how structural considerations influenced the architectural design. Learn how your appreciation of great architectural works can be enriched through an understanding of basic structural mechanics principles.

Anthropology

Speaker: Kenneth Harl, Ph.D.

Why Was There a Viking Age?

Learn how the harsh climate and daunting geography of Scandinavia shaped the unique culture and religion of the Nordic peoples of the Viking Age. The Scandinavians produced superb ships, excelled in warfare, celebrated ancestral heroes and worshiped frightening gods. We'll look at how the many strands of Viking life tied together.

Viking Voyages of Discovery

Learn how Vikings braved the North Atlantic in spectacular voyages of discovery that led to the colonization of the Faroe Islands, Iceland, Greenland, and Newfoundland. Hear about the exploits of Erik the Red, Leif Eriksson and other Nordic explorers, their remarkable ships and seamanship, and the peculiar legacy of faked Viking artifacts from this time.

The Icelandic Republic: A Frontier Society

Learn how Icelanders created the first overseas European colonial society and established a remarkably successful form of government and a rich literary tradition. We'll examine records of family sagas to learn about the lives, loves and disputes of ordinary men and women in Viking Age Iceland.

Poetry and Saga of the Viking Age

Viking Age Icelanders developed a genius for reciting poetry and storytelling—skills prized for entertainment during the long winters. We'll read poems replete with subtle metaphors and composed in an array of alliterative verses, as well as prose narratives that stand among the finest vernacular literature of Medieval Europe.

Vikings in Hollywood

We'll take an entertaining look at novels, comics and movies that have popularized the image of barbaric Vikings sporting horned helmets. While it is easy to dismiss Hollywood for sensationalism, it is remarkable how well some examples have recreated the spirit of the Viking Age.

Neuroscience

Speaker: Martha J. Farah, Ph.D..

Cognitive Enhancement: the Neuroscience of Boosting Your Brainpower

Can a pill make you smarter? Hear the latest on the neural bases of intelligence and methods for enhancing it, including psychopharmacology, transcranial brain stimulation and "brain-training" programs. We'll also consider the ethical, legal, and societal impact of these practices.

Wellbeing and the Brain

Whatever wellbeing means to you, chances are the brain plays an important role in attaining and maintaining it. Learn about the neural bases of mood and resilience, and how exercise, sleep, social connectedness and meditation can improve these functions and the brain systems that support them.

Neurolaw

"Ladies and gentlemen of the jury, do not condemn my client for his actions. He had no choice in the matter; events set in motion at the time of the big bang resulted in his brain functioning as it did on that fateful day." Would you be persuaded by this lawyer's defense? We'll explore the fascinating intersection of ethics, law and neuroscience.

How Genes and Experience Make Us Who We Are

From prenatal processes of cell creation and migration in the fetal brain to the sculpting of neural connections in adolescence, human brain development is a complex and prolonged process. We'll discuss genetic influences on intelligence, personality and other reflections of brain function, and how each individual's life experiences influence the development and function of the brain.

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Saturday, August 1st

Find your own version of London amidst its many layers and neighborhoods. Museums and parks, tradition and innovation, urban vitality and peaceful corners are all up for your exploration.

For more info please email Info@InsightCruises.com or visit ScientificAmerican.com/travel

MORE TO EXPLORE For more recommendations and an interview with author John Scalzi, go to ScientificAmerican.com/nov2014/recommended

Fiction from Fact

A provocative crop of science-informed fiction speculates about futuristic medicine, galactic civil war and virtual murder

Lock In

by John Scalzi. Tor,* 2014 ($24.99)

In this near-future murder mystery, a virus has swept the world, causing some who are infected to be "locked in" to their bodies—unable to talk, move or respond to stimuli but nonetheless aware. Technology that is developed in response to the crisis allows the afflicted to mentally inhabit robotic bodies, leaving their paralyzed human shells behind. The technology grants those locked in special powers, such as the ability to move instantly from a robotic body in one location to another far away, as well as to participate in a rich virtual-reality environment created just for them. Scalzi's tale explores whether, in those circumstances, being locked in is still a disability and whether it should be cured, among other questions of technology, ethics and politics.

The Peripheral

by William Gibson. G. P. Putnam's Sons, 2014 ($28.95)

Famed speculative-fiction author Gibson writes of a noir reality where technology dominates a society possessing mind-controlled smartphones, an advanced Web that permits time travel, and robots that appear human but are actually mentally remote-controlled by people. In this dark, Big Brother–esque world, the main characters live in near and distant futures connected by a wireless device called "the server." An unknown employer hires the story's heroine, Flynne, to beta-test a virtual game. While playing, she accidentally witnesses a homicide and soon discovers that the game is actually a window into the future. She has no choice but to traverse time to help solve the whodunit.

—Annie Sneed

Ancillary Sword

by Ann Leckie. Orbit, 2014 ($16)

This follow-up to the Hugo Award–winning novel *Ancillary Justice* tells the story of Breq, a soldier who once controlled many bodies, and even an entire starship, through artificial intelligence but is now left stranded in a single human frame. Breq has achieved a measure of vengeance for the act that stripped her of her bodies and is now forging a new path for herself in an empire on the brink of a galaxy-spanning civil war. She must learn how to command a new ship and a crew beyond her mental control. Through a unique use of language—Breq's people barely notice gender and use only female pronouns—and a thoroughly drawn culture with intricate rules, Leckie investigates what it means to be human, to be an individual and to live in a civilized society.

Symbiont

by Mira Grant. Orbit, 2014 ($26)

In this book, the second in Grant's Parasitology series of thrillers, a medical breakthrough is not all that it seems. Most of the world lives with implanted genetically engineered tapeworms that boost the immune system, protect against illness and secrete helpful drugs. The powerful biotech company behind the worms has an interest in keeping any risks under wraps, but a serious danger becomes public when a zombielike sleepwalking sickness begins infecting people. Now scientists who created the extraordinary worms have to grapple with a creation they can no longer control.

*SCIENTIFIC AMERICAN AND TOR ARE AFFILIATES

Illustration by Tom Whalen

PROMOTION

The Agenda Setters

Bringing Science to Life








Science of Learning

Asia Society | New York, NY | August 5, 2014

Our 2nd Annual Executive Summit brought together experts from SCIENTIFIC AMERICAN, Macmillan Education and Macmillan New Ventures to lead the discussion on engaging students in STEM. Announcements about the winner of the SCIENTIFIC AMERICAN Science in Action Award and the Macmillan Education grant for cross-sector collaboration further inspired the participants to think about innovation in education.

Pictured above (clockwise from top left): **Nicholas Smith**, HotChalk, **Susan Winslow**, Macmillan Education, **Mariette DiChristina**, Scientific American, **Dr. Russell Shilling**, U.S. Department of Education, **Keith McAllister**, Scientific American, **Dr. Julia Phelan**, UCLA, **Dr. Ryan Baker**, Columbia University, **Dr. Ainissa Ramirez**, **Dr. Mark McDaniel**, Washington University in St. Louis, **Dr. Joy Reidenberg**, PBS Host/Contributor and Icahn School of Medicine at Mt. Sinai, **Cristin Frodella**, Google and **Dr. Carl Wieman**, Stanford University

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

Perpetual Peace

Are democracies less warlike?

From Ukraine, Syria and Gaza to the centenary of the First World War in 2014, news junkies and students of history cannot help but wonder if war is a perpetual feature of civilization. German philosopher Immanuel Kant wondered as much in a 1795 essay entitled "Perpetual Peace," concluding that citizens of a democratic republic are less likely to support their government in a war because "this would mean calling down on themselves all the miseries of war." Ever since, the "democratic peace theory" has had its supporters. Rutgers University political scientist Jack Levy, in a 1989 essay on "The Causes of War," reasoned that the "absence of war between democratic states comes as close as anything we have to an empirical law in international relations." Skeptics point out such exceptions as the Greek and Punic wars, the War of 1812, the U.S. Civil War, the India-Pakistan wars and the Israel-Lebanon War. Who is right? Can science answer the question?

In their 2001 book *Triangulating Peace,* political scientists Bruce Russett and John Oneal employed a multiple logistic regression model on data from the Correlates of War Project that recorded 2,300 militarized interstate disputes between 1816 and 2001. They assigned each country a democracy score between 1 and 10, based on the Polity Project, which measures how competitive its political process is, as well as the fairness of its elections, checks and balances of power, transparency, and so on. The researchers found that when two countries scored high on the Polity scale, disputes between them decreased by 50 percent, but when one country was either a low-scoring democracy or an autocracy, it doubled the chance of a quarrel between them.

Kant also suggested that international trade (economic interdependency) and membership in international communities (transparency and accountability) reduce the likelihood of conflict. So in their model Russett and Oneal included data on the amount of trade between nations and found that countries that depended more on trade in a given year were less likely to have a militarized dispute in the subsequent year. They also counted the number of intergovernmental organizations (IGOs) that every pair of nations jointly belonged to and ran a regression analysis with democracy and trade scores. Overall, democracy, trade and membership in IGOs (the "triangle" of their title) all favor peace, and if a pair of countries are in the top 10th of the scale on all three variables, they are 81 percent less likely than an average pair of countries to have a militarized dispute in a given year.

How has the democratic peace theory held up since 2001? With all the conflict around the world, it seems like peace is on the rocks. But anecdotes are not data. In a 2014 special issue of the *Journal of Peace Research,* Uppsala University political scientist Håvard Hegre reassessed all the evidence on "Democracy and Armed Conflict." He stated that "the empirical finding that pairs of democratic states have a lower risk of interstate conflict than other pairs holds up, as does the conclusion that consolidated democracies have less conflict than semi-democracies." Hegre is skeptical that economic interdependence alone can keep countries from going to war—the "Golden Arches Theory of Conflict Prevention" popularized by Thomas Friedman's observation that no two countries with McDonald's fight—unless their economies are in democratic nations. He wonders, reasonably, if there might be some other underlying factor that explains both democracy and peace but does not suggest what that might be. I propose human nature itself and our propensity to prefer the elements of democracy. Peace is a pleasant by-product.

Whatever the deeper cause may be, the long-term trends are encouraging. According to Freedom House, there were no electoral democracies (with universal suffrage) in 1900, 69 in 1990, and 122 in 2014—63 percent of the 195 countries in the world. That's moral progress. The other 37 percent—particularly the theocratic autocracies desirous of thermonuclear weapons and bent on bringing about Armageddon—means we must remain vigilant. Otherwise we run the risk that Kant's perpetual peace will dissolve into the source of his essay title's inspiration: an innkeeper's sign featuring a cemetery. This is not the type of perpetual peace toward which most sentient beings strive. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2014

Illustration by Izhar Cohen

November 1964

Hemoglobin Protein

"In its behavior hemoglobin does not resemble an oxygen tank so much as a molecular lung. Two of its four chains shift back and forth, so that the gap between them becomes narrower when oxygen molecules are bound to the hemoglobin, and wider when the oxygen is released. Evidence that the chemical activities of hemoglobin and other proteins are accompanied by structural changes had been discovered before, but this is the first time that the nature of such a change has been directly demonstrated. Hemoglobin's change of shape makes me think of it as a breathing molecule, but paradoxically it expands, not when oxygen is taken up but when it is released. —M. F. Perutz"

Perutz shared the 1962 Nobel Prize in Chemistry for this work.

Food Bubbles

"The bubbles made by waves at sea have been found to make a vital contribution to the oceanic food chain. Molecules from the vast supply of organic chemicals dissolved in seawater adhere in large numbers to the air bubbles' two-dimensional boundary layers. In the process they form clumps of organic matter that are eaten by the smallest members of the marine animal population. The discovery of the new food-producing mechanism resulted from the dissatisfaction of some marine biologists with the traditional view of the pyramid of oceanic life. It was pointed out that the quantity of organic matter in suspension or in solution in the oceans is at least 50 times greater than that contained in all living plankton."

November 1914

The Wounded in This War

"That the wound made by the modern high velocity bullet, covered with its nickel jacket, is more or less aseptic, and that a large proportion of the wounds made by them are not of a serious nature, and give but little trouble, has been demonstrated. In this respect the work of the army surgeon of the present day has certainly been simplified, and the percentage of fatalities from bullet wounds in the present war will show a material decrease [*see photograph*]."

Water for Transport

"One of the large industrial problems of the times is the transportation of raw material. In the case of timber logs, they will often be cut far up on the mountain side, or in a swamp or exceedingly distant from the sawmill. Impelled, no doubt, by considerations such as these, Capt. H. R. Robertson undertook thirty years ago to construct a raft of logs in Nova Scotia, and then to bring it to New York in care of a towing tug. Capt. Robertson has now transferred his operations to Coal Creek. Here rafts are still built and floated out to sea via the Columbia River. They are towed down the coast to San Francisco—a distance on the sea of 500 or 600 miles. The material that is brought in this way consists only of timbers suitable for piles."

A slide show of images from our 1914 archives on the use, control and engineering of water is at ScientificAmerican.com/nov2014/water-control

November 1864

Presidential Election

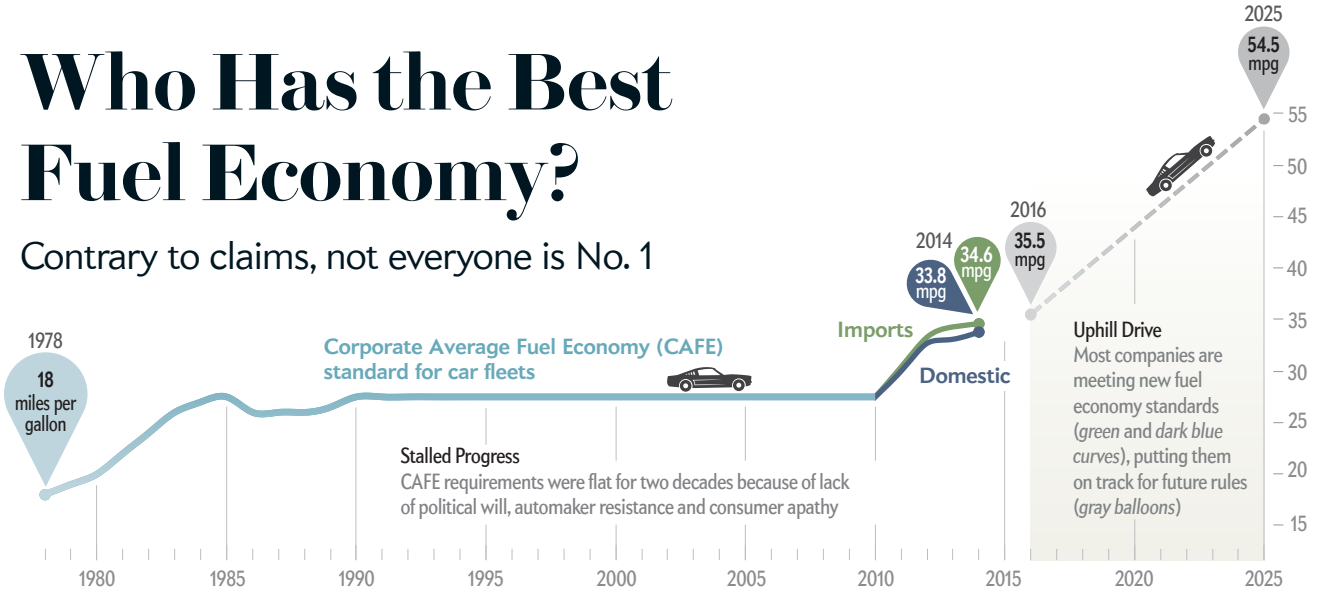
"ABRAHAM LINCOLN, of Illinois, has been re-elected President of the United States by a large popular majority; and ANDREW JOHNSON, of Tennessee, has been chosen Vice President, to succeed Hannibal Hamlin, of Maine. The election passed off peaceably and without the necessity of military interference; and it now becomes citizens of all parties to yield a willing and cheerful obedience to the authorities thus constituted by the popular suffrages. Under our constitutional Government such obedience is absolutely requisite to the permanent safety and prosperity of the Republic; for unless this Government be upheld by the united strength of the people its destruction will ensue; order will give place to anarchy, and anarchy will be succeeded by a despotic power supported by military force and violence. We have already witnessed the direful consequences of a rebellion against the rightfully-chosen leaders of this nation, the sad effects of which will exist for a generation at least."

FRENCH ARMY cavalry soldiers (cuirassiers) "assisting a wounded comrade," according to the caption from 1914.

PHOTOGRAPH BY MEURISSE IN *SCIENTIFIC AMERICAN SUPPLEMENT*, VOL. LXXVIII, NO. 2029, NOVEMBER 21, 1914

Who Has the Best Fuel Economy?

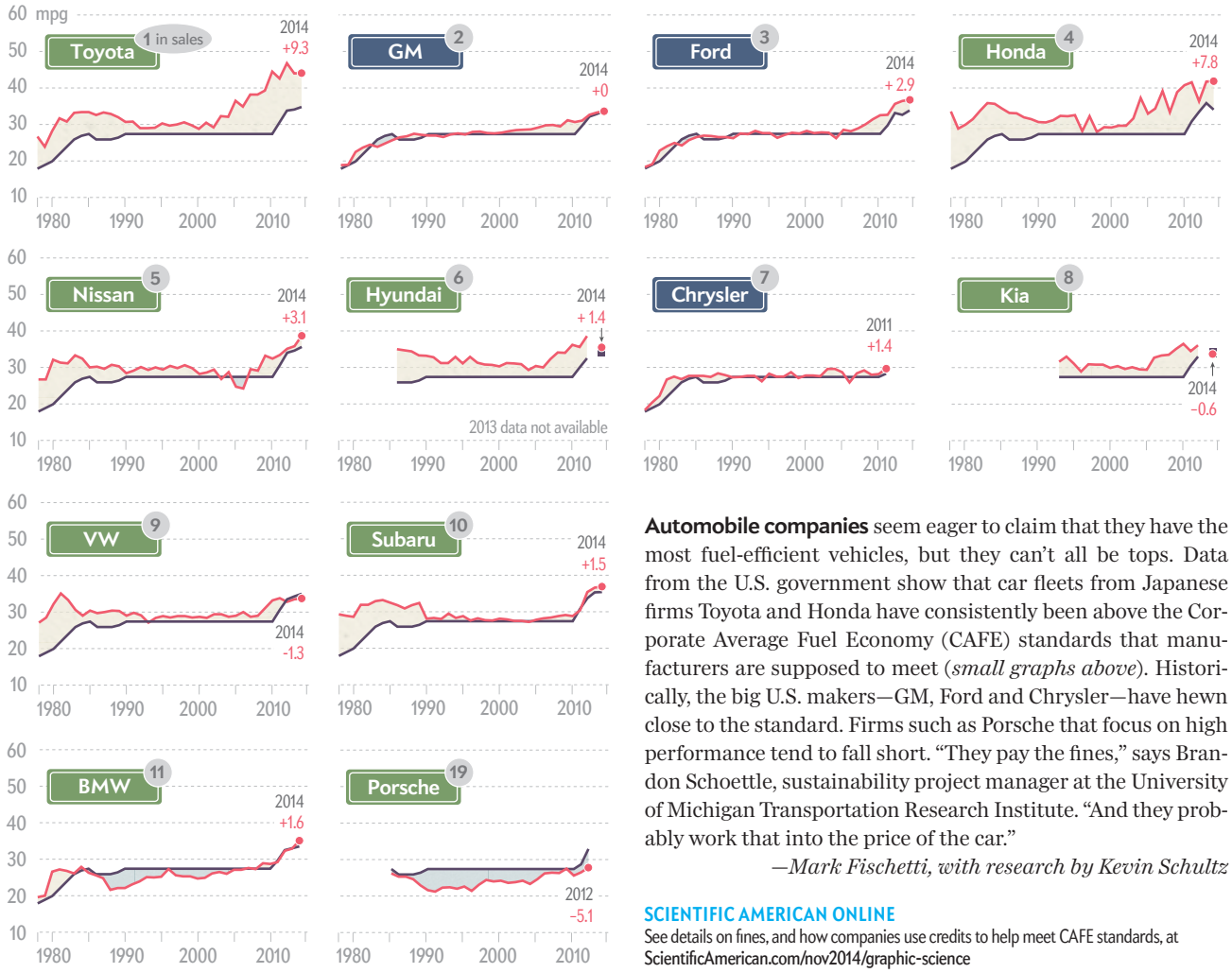
Contrary to claims, not everyone is No. 1



Car Fleet Efficiency (arranged by 2013 sales in the U.S., most to least)

CAFE standard to be met*
Actual performance achieved
Domestic cars (made in U.S.)
Imported cars (made outside U.S.)†

*U.S. government weights the standard to each company's mix of vehicles. †Some companies, such as Toyota, make cars inside and outside the U.S. for the U.S. market; only one group is shown.



Automobile companies seem eager to claim that they have the most fuel-efficient vehicles, but they can't all be tops. Data from the U.S. government show that car fleets from Japanese firms Toyota and Honda have consistently been above the Corporate Average Fuel Economy (CAFE) standards that manufacturers are supposed to meet (*small graphs above*). Historically, the big U.S. makers—GM, Ford and Chrysler—have hewn close to the standard. Firms such as Porsche that focus on high performance tend to fall short. "They pay the fines," says Brandon Schoettle, sustainability project manager at the University of Michigan Transportation Research Institute. "And they probably work that into the price of the car."

—Mark Fischetti, with research by Kevin Schultz

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See details on fines, and how companies use credits to help meet CAFE standards, at ScientificAmerican.com/nov2014/graphic-science

SOURCES: *SUMMARY OF FUEL ECONOMY PERFORMANCE*. U.S. DEPARTMENT OF TRANSPORTATION, MARCH 2004 AND JUNE 26, 2014 (*CAFE and fleet performance data*); *WALL STREET JOURNAL* MARKET DATA CENTER *http://online.wsj.com/mdc/public/page/2_3022-autosales.html* (*sales rankings*).

Graphic by Jane Pong

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 34 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

The Call of the Mild

A late summer science trip in the 49th state

Meyer Landsman, the Sitka, Alaska–based protagonist of Michael Chabon's award-winning novel *The Yiddish Policemen's Union,* "swayed in the canvas webbing of the weary old 206." The 206 is a single-engine Cessna that can be converted to a floatplane, a factoid I happened to know when I read that line late on August 28 because earlier that day I rode shotgun in a 206 that took off from the water strip that parallels the main runway at Juneau International Airport. This 206 dipped me between mountains for an astounding view of the nearby Casement and Davidson glaciers.

The obvious question now is, How did a nice Bronx boy, who knows the Lexington Avenue subway line like an Iditarod musher knows her dogs, get to bouncing around low and slow over ice fields a short jump from Sitka? On a *Scientific American*/Bright Horizons cruise, *kaynahora,* organized by Neil Bauman and Theresa Mazich of Insight Cruises. They create the cruises and other special-interest trips with an intellectual appeal. Despite that cerebral qualification, I was invited along on the Alaska edition. The voyage consisted of two weeks onboard the Holland America Line's MS *Amsterdam,* as we visited the hot spots of southeast Alaska. I learned that a "sliming table" can refer to a workplace in a salmon-processing plant. In New York City, it's what we sit around to discuss friends and family.

In the face of seemingly uninterrupted opportunities to enjoy caloric intake both on and off the ship, I managed to actually lose weight on the cruise. This paradoxical feat was achieved through a combination of techniques. First, portion control. No need to eat everything at the buffet when you realize that you can try the Baked Alaska, of course on the menu, at the next of the approximately 40 shipboard meals. Second, choose the fish. Watching black bears plucking salmon from a stream outside of Ketchikan naturally gives one a hankering for the same meal, albeit perhaps cooked on a cedar plank. Third, always take the stairs, although I sometimes peeked into the ship's elevator for vital information—a floor mat announces the day of the week. That policy may seem comical until you've been at sea for a week and a half: What's a "Tuesday"?

Besides fish, I ingested fillets of knowledge. When at sea, we were treated to some 25 sessions with a diverse faculty, including Larry Cahill, neurobiologist at the University of California, Irvine; Robert Fovell, atmospheric and oceanic scientist at U.C.L.A.; James Gillies, head of communications at CERN; Peter Smith, professor emeritus of planetary sciences at the University of Arizona; and David Stevenson, planetary scientist at the California Institute of Technology.

Listen for clips from some of these lectures on the *Scientific American* Science Talk podcast, including Fovell's explanation as to why the notion of a freezing air mass that descends on New York City in the movie *The Day After Tomorrow* is goofy. "Instead of that air coming down at –80 degrees Fahrenheit, its original temperature perhaps at the tropopause, the top of the lowest layer of the atmosphere, it should come down and compress at the dry adiabatic lapse rate, which is 30 F per mile … by the time [the air] reaches the ground, it should have been about 140 degrees F." We all knew that movie was a hot mess.

Cahill discussed the recently discovered phenomenon of HSAM, highly superior autobiographical memory. The handful of people with HSAM have an uncanny ability to catalogue and retrieve information about their experiences on pretty much every day of their lives after young childhood. (An unusually developed bundle of brain tissue called the uncinate fasciculus looks like it may be involved in the condition.) Actor Marilu Henner is among them and was asked, during an interview with Bob Costas, about her activities on various dates, including that of the first manned moon landing. At the mention of July 20, 1969, Henner became a bit embarrassed because, she eventually revealed, that same night she lost her virginity. To which Costas replied, "Well, one thing we know for sure, Neil Armstrong wasn't the culprit."

After that memory talk, a participant asked Cahill if he'd ever thought of asking one of the HSAM folks, "Do you only go on a vacation once and just think about it again? You'd save a lot of money." To which Bauman, rumbling like a calving glacier, shouted, "Shame on you!" SA

SCIENTIFIC AMERICAN ONLINE
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Illustration by Matt Collins

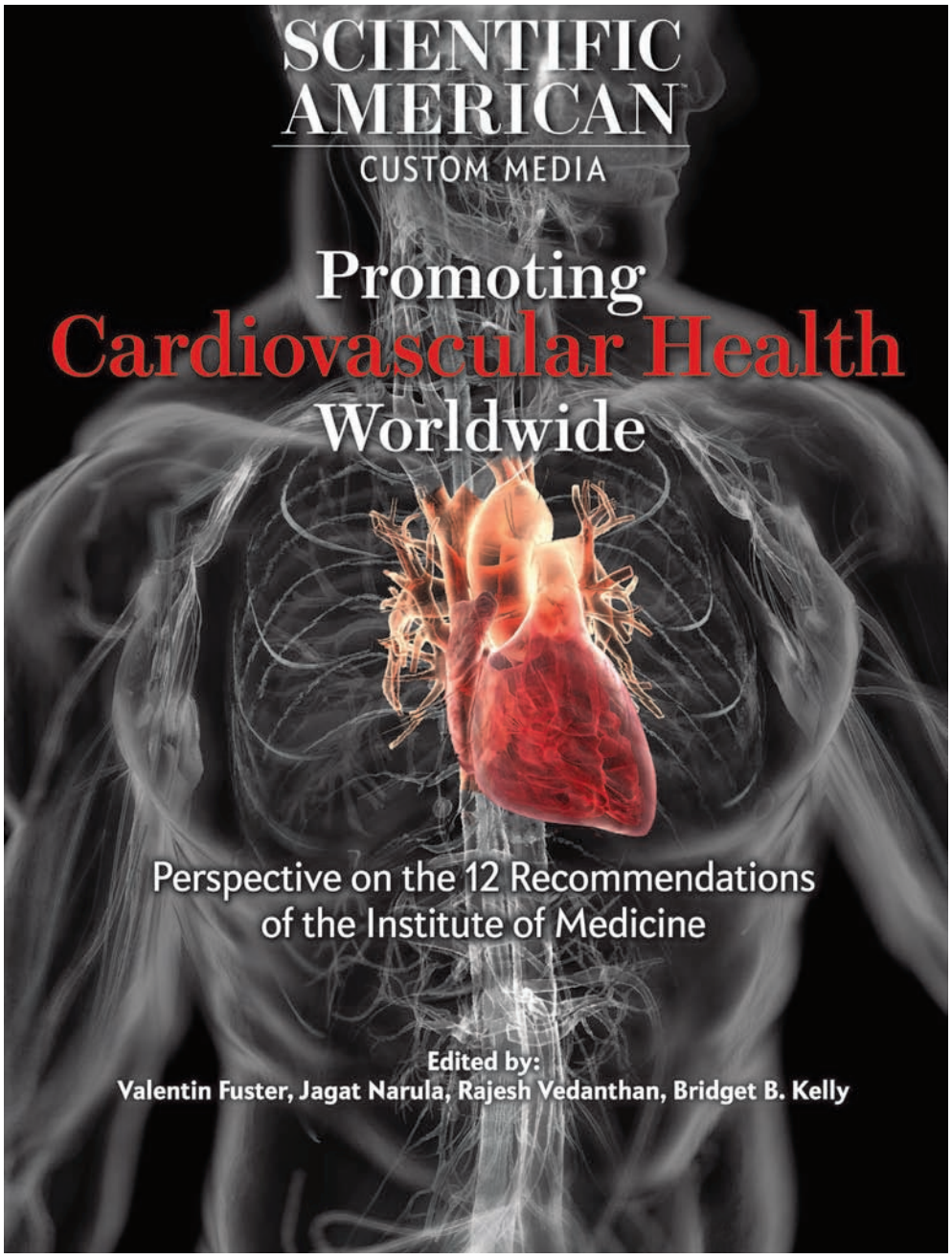
PROMOTING **CARDIOVASCULAR** HEALTH WORLDWIDE

A compelling look at one of the most pressing issues of our time...

Heart disease and related non-communicable diseases were once considered a problem that only wealthy, industrialized nations faced. Together, they now rank as the leading cause of death across the globe.

This special issue, ***Promoting Cardiovascular Health Worldwide***, explores the problem – and outlines the solutions.

Brought to you by SCIENTIFIC AMERICAN CUSTOM MEDIA and ICAHN SCHOOL OF MEDICINE AT MOUNT SINAI — this special issue is a follow up on the 12 Recommendations from the Institute of Medicine for promoting cardiovascular health in the developing world.



For a free digital issue visit:
ScientificAmerican.com/products/cardiovascular-health

Another case of a Subaru going places others don't.

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