BIOMECHANICS
Secret to Olympian Speed

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A "Macroscope" for Humanity's Health

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The Emptiest Place in Space

A pocket of (almost) nothing tells us something about the cosmos

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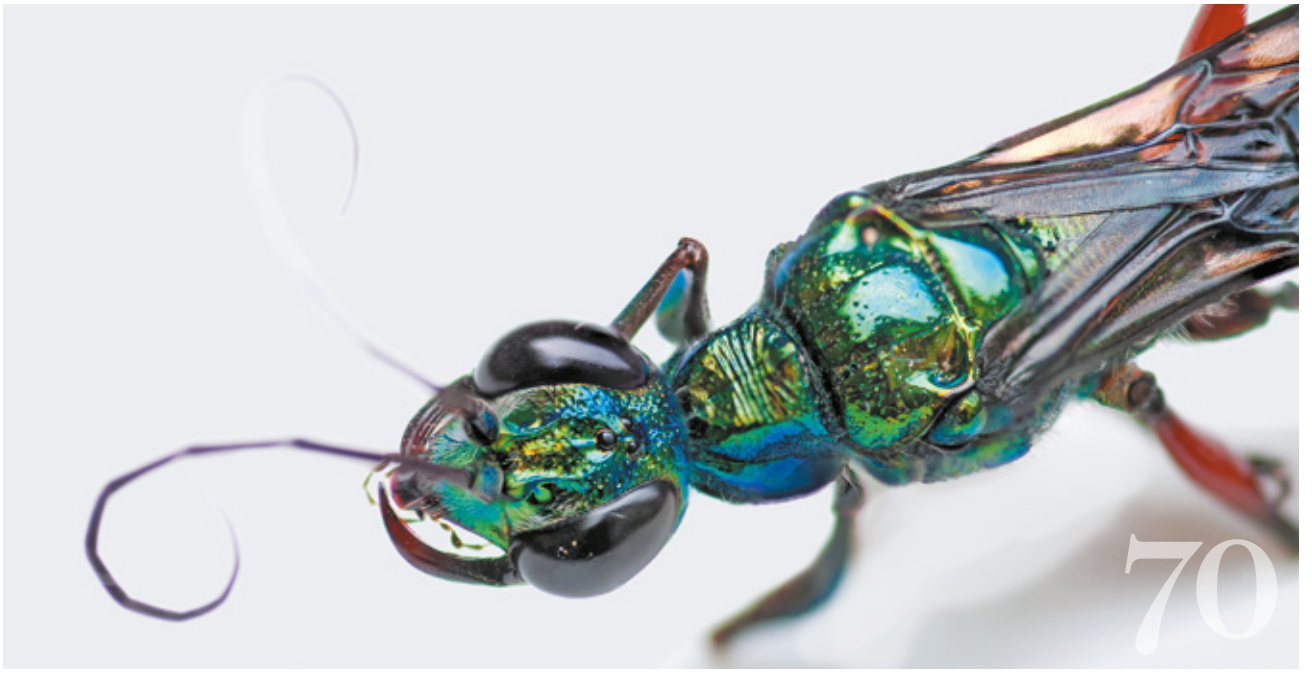

ON THE COVER
Astronomers have recently discovered a cosmic supervoid—an immense area of space that is curiously devoid of galaxies, stars and other matter. By sapping energy from light that passes through it, the supervoid may help explain an unusual cold spot in the cosmic microwave background light pervading the universe.
Image by Kenn Brown, Mondolithic Studios.

KIMIE SHIMABUKURO *Getty Images*

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ON THE WEB

Facebook Experiments with AI
Scientific American discusses artificial-intelligence research with pioneer Yann LeCun, who leads Facebook's efforts to build a smarter social media site.
Go to www.ScientificAmerican.com/aug2016/internet-ai

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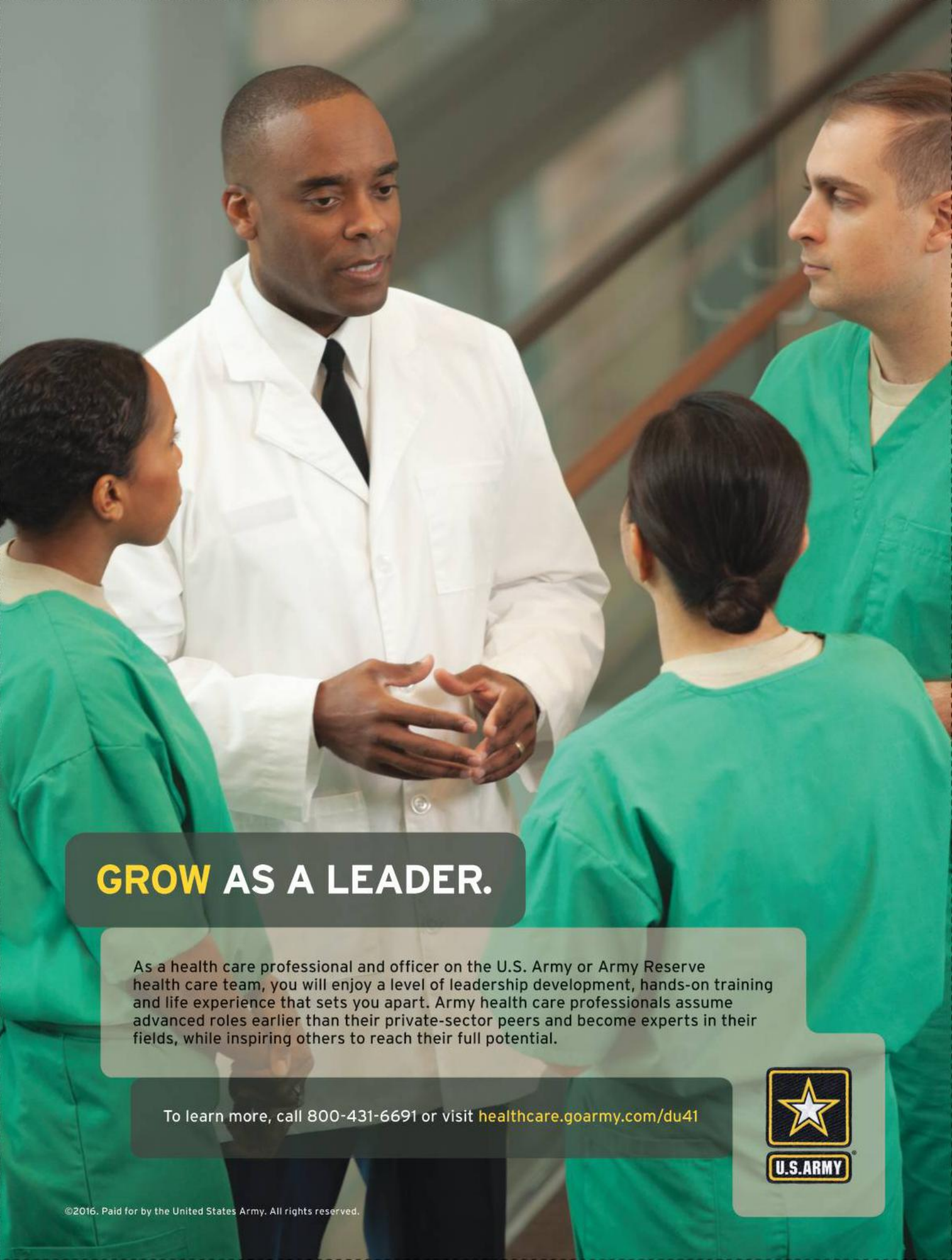

Mariette DiChristina is editor in chief of *Scientific American*. Follow her on Twitter @mdichristina

The Treasure Hunt Is On

My father once advised me to try to learn something new every day. Fortunately, *Scientific American* always delivers. And even the most seemingly esoteric feature articles have down-to-earth details or surprising facts that help make them relevant and accessible. Consider this our invitation to this issue's knowledge treasure hunt.

Take our cover story, "The Emptiest Place in Space," by István Szapudi. Our astronomer author probes the origin of an odd "cold spot" in the cosmic microwave background, the light that rippled from the big bang throughout the universe. What caused this vacant place? Szapudi outlines a theory of a giant supervoid. You will also learn the answer to this question: What household appliance can you use to detect the most ancient light in the universe, 13.8 billion years old? To find out, you'll have to turn to page 28.

The supervoid extends 1.8 billion light-years across; sometimes you need just the right vantage point to understand large-scale problems such as how the universe evolved. For people on Earth, a new, expansive perspective on the species can come from something called the macroscope, the conceptual opposite of the microscope. The "instrument," made of software and big data, can analyze health statistics from all over the planet to create a picture of humanity's health in more detail than ever possible before. What kind of computing power do you need to create a health report card for our species? Read all about it in "Health Check for Humanity," by contributing editor W. Wayt Gibbs, which starts on page 36.

With the return of the Summer Olympics, we take a closer look at the "The Secret to Speed" in sprinters, by staff writer Dina Fine Maron. The conventional wisdom that the key is repositioning limbs while in the air to step faster turns out to be wrong. Instead top sprinters swiftly zoom along by applying multiple times their body weight to the ground. How many times? Go to page 50.

You can explore many more topics elsewhere in the issue: what real-life Earth-dwelling denizen gave scriptwriters the idea for chest-bursting horrors in the *Alien* movie series ("Zombie Neuroscience," page 70); what species bequeathed to humans the Huntington's gene and why its normal form is beneficial ("The Huntington's Paradox," page 56); and even (wink) why the U.S. Navy uses blue camouflage (Anti Gravity, page 76). If you unearthed a favorite new fact or insight, we'd enjoy hearing about it. SA

Illustration by Maria Corte Maidagan (supervoid), Illustration by Nick Higgins (DiChristina)

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April 2016

PROBLEM OF NUCLEAR WASTE

In "Stop Dithering on Nuclear Waste" [Science Agenda], the editors argue that the U.S. needs to create a deep repository for nuclear waste and should revisit its decision to close the proposed Yucca Mountain repository in Nevada. I agree that Yucca Mountain should be revisited. I think a series of town hall–type meetings could be set up to inform the public about the issue.

I also think that all presidential candidates should be asked what they would do about nuclear waste handling. This could be achieved by including the issues in debates and forums that are already scheduled or by sending letters or e-mails to the respective campaign offices.

Stephen A. Hodgson
Galveston, Tex.

So the editors think it is a great idea to place nuclear waste in the "barren" Yucca Mountain site, do they? Out of the 99 nuclear power plants operating today, only a handful are located west of eastern Texas. Clearly unlike the West, the eastern portion of our nation has embraced nuclear power in a big way and now wants to dump their garbage in someone else's backyard.

How to dispose of the nuclear waste has always been an afterthought to proponents of atomic energy, but that waste makes it a stillborn idea. No one wants to store it on-site because of the inherent dangers of doing so. Transporting the waste via rail or truck presents dangers all its own, but after the waste passes to the West, most Easterners would stop caring what happens to it.

"How to dispose of the nuclear waste has always been an afterthought to proponents of atomic energy."

KIRK WAYLAND *IRVINE, CALIF.*

Kirk Wayland
Irvine, Calif.

MEASUREMENT MYSTERY

In "The Neutron Enigma," Geoffrey L. Greene and Peter Geltenbort describe an approximately nine-second difference in the two most precise measurements of the neutron's lifetime and explain how one of the measurements uses what is called the "beam method" and the other the "bottle method."

Is it possible that the beam method shows a longer neutron lifetime than the bottle method because of time dilation of the neutrons' speed?

David Lapadula
Raleigh, N.C.

It would seem that, as the authors did mention, a strong argument could be made that the differences observed were related to the different methods used. What if the electromagnetic field has some effect on the neutron decay process?

Loretta Brown
Grand Blanc, Mich.

THE AUTHORS REPLY: Like Lapadula, several readers thoughtfully suggested that relativistic time dilation might explain the discrepancy because of the difference in neutrons' velocity in the two approaches. This is a real effect, and it is known that the lifetime of an unstable particle moving at a speed approaching the speed of light is longer when it is measured in the laboratory rest frame than when it is measured in the frame of the moving particle. In the beam experiment, the typical neutron speed is about 1,000 meters per second; in the bottle experiment, it is only a few meters per second. But these speeds are far less than the speed of light, and so the effect is very small. The lifetime difference caused by the relativistic effect is only a few nanoseconds, or only about a billionth of the observed effect.

Regarding Brown's question: Quite a few readers were also concerned about the fact that in the beam experiment, the decaying neutrons were in a magnetic field, whereas in the bottle, there is no field. In fact, if the magnetic field were extremely intense (far, far stronger than in the real experiment), its effect on the outgoing charged particles (electrons and protons) would change the lifetime to a detectable degree. This effect can be reliably estimated because the dynamics of neutron decay are well understood. For any practical laboratory magnetic field, the effect is far too small to cause a detectable change. More recent experiments with magnetic traps, in which there is a strong magnetic field, are consistent with this analysis.

GALÁPAGOS TOURISM

In "Galápagos Stampede," Paul Tullis describes the conflict facing Ecuador's government between the need to cap the number of visitors to the Galápagos Islands at a level that doesn't threaten their unique ecosystem on the one hand and the need for greater revenue from tourism on the other. This appears to be a classic case of an economics problem for which the solution is well known: charge a (higher) fee.

There should be a permit required for foreign tourists wishing to visit any part of the islands, with the cost set high enough that visitors will self-cap at the desired level.

David Hoffman
via e-mail

BRAIN EVOLUTION

In "Tales of a Stone Age Neuroscientist," Dietrich Stout describes research supporting the idea that the evolution of the human brain was encouraged by the development of stone tools. But he does not mention another, possibly parallel technical

development that did not leave many archaeological traces: string.

The act of twisting plant fibers and tying knots requires careful use of an opposable thumb and may have helped develop human dexterity and the fine control of a precision grip.

COLIN LEDSOME
London

Stout ignores the most obvious source of linguistic evolution in the human brain: communication between mothers and children. Toolmaking is essentially silent and solitary, whereas child-rearing is noisy and communal. The slow development of human children is thus as likely a source for the emergence of language as the knapping of flint.

BARBARA WILSON
Newport, Ore.

TERMS OF ACHIEVEMENT

In his Skeptic column, Michael Shermer describes Deepak Chopra's statement that "attention and intention are the mechanics of manifestation" as nonsense in "Hooey. Drivel. Baloney …" But it has real meaning to people who participate in that self-reflective mode of being called mindfulness. Contrary to Shermer's skepticism, the effort that leads to manifesting mindfulness most definitely requires the mechanics of attention and intention.

BILL HAXTON
Three Rivers, Calif.

CLARIFICATION

"The Paradox of Precision Medicine," by Jeneen Interlandi [The Science of Health], stated that because a lot of tumors eventually developed mutations that rendered the malignancies resistant to the cancer drug Gleevec, that drug was able to buy patients with a particular form of leukemia a little time but did not change their final outcome. The article should have qualified that whereas many patients experienced those disappointing results, the drug has helped a number of people live eight years or more.

ERRATUM

"Quick Hits" [Advances] incorrectly said the next Square Root Day would occur in 11 years. The next one is in nine years.

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Olympic Officials Should Tell Women "High T" Is No Hurdle

It is unscientific and unfair to bar female athletes with elevated testosterone

By the Editors

Four years ago Indian sprinter Dutee Chand seemed headed for greatness. She became her country's 100-meter champion for women 18 and younger, and the Sports Authority of India called her a "sure shot Olympic medalist." Yet soon afterward, the Athletics Federation of India banned her from competition because she had an elevated level of the hormone testosterone, the result of a natural condition called hyperandrogenism.

Chand appealed the ruling to the Switzerland-based Court of Arbitration for Sport (CAS), and she won. The decision should allow women with naturally "high T" to compete in all international track competitions. But the International Olympic Committee (IOC), which has banned such female athletes from prior games, has not come out to support the CAS decision. As the Summer Olympic Games in Rio de Janeiro approach, the ambiguity could prevent women with conditions such as Chand's from competing on sports' brightest stage.

This ongoing state of limbo is a mistake. There is no scientific basis for barring these women. Hormone levels akin to Chand's are natural, and there is no evidence that they enhance performance (unlike the doping efforts of the Russian team during the 2014 Sochi Winter Games that were revealed this past spring). Worse, attempts to reduce high testosterone levels below levels specified by the IOC carry serious medical risks for women.

The official Olympic testosterone cutoff for female athletes is 10 nanomoles per liter, but some go beyond it, into the "male" range, and some men fall into the "female" range, thanks to normal hormonal fluctuations that differ from individual to individual. Moreover, high T is not always synonymous with good performance. Some top-level male athletes have testosterone levels that dip into the female range, for example: one recent study of 693 elite athletes in *Clinical Endocrinology* found that 16.5 percent of males had testosterone levels that were below the male range and almost 2 percent fell in the female range. And almost 14 percent of the women were above the permissible maximum for female athletes.

Things would be different if women were suspected of deliberately taking extra testosterone in the hope—legitimate or not—that it would boost their performance. Even then, existing tests could easily ferret out the subterfuge because naturally occurring testosterone has a different mix of carbon isotopes than an artificially introduced hormone. Tests that detect this artificial signature are already used on suspect male athletes. But if officials determine that a male competitor's unusually high T is natural, the investigation stops. Fairness and science both dictate that women should be treated exactly the same.

Forcing women athletes to bring their natural testosterone down to an "acceptable" level is also potentially dangerous. They would have to take hormone-suppressing drugs or have surgery to remove hormone-producing organs. There is no medical reason for a healthy woman to undergo such treatments, which carry risks of serious side effects, such as an electrolyte imbalance that can cause irregular heartbeats. Other effects include nausea, as well as excessive thirst and urination.

During the Sochi and the 2012 London Olympics, the IOC had invoked its arbitrary standard to ban several women. This year the committee has signaled, in response to questions from *Scientific American* and other media, that it will not take such action. But the absence of an official statement leaves plenty of uncertainty. Countries could easily continue to disqualify female competitors at preliminary competitions, cutting short their Olympic chances, says Stanford University bioethicist Katrina Karkazis.

Elite athletes are by definition physiological outliers because of their strength, speed and reflexes. Natural hormonal variations, similar to other intrinsic biological qualities—superior oxygen-carrying capacity in the blood, for example—are part of that mix. The IOC should say so explicitly. SA

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Illustration by Cat O'Neil

Thomas Hartung is a professor of toxicology, pharmacology, molecular microbiology and immunology at Johns Hopkins Bloomberg School of Public Health.

The Lesser Evil of E-Cigarettes

They are undoubtedly harmful but far better than tobacco products

By Thomas Hartung

No one disputes the fact that cigarette smoking kills, although many people might not realize just how lethal it really is. The World Health Organization estimates that tobacco kills up to one half of its regular users via cardiovascular disease, lung and other cancers, and respiratory illnesses. About 30 percent of current U.S. cancer deaths result from tobacco use.

Electronic cigarettes, however, are taking over at an astonishing pace. They were introduced in the early 2000s, and according to some experts, sales could exceed those of traditional tobacco products within a few years. In reaction, the U.S. Food and Drug Administration announced in May that it would ban sales to individuals younger than 18; it would also require manufacturers to register their products with the agency and submit ingredients for safety testing. Some countries, such as New Zealand, ban e-cigarettes that contain nicotine entirely.

Policies that restrict e-smoking are reasonable. We don't know yet what kind of health risks it carries, so we don't want people who don't smoke—especially kids—to take it up. And yet we should keep in mind that such vaping is almost certainly safer than conventional smoking: some experts have suggested that e-cigarettes carry only between 3 and 5 percent of the health risks of tobacco smoking. We don't want to ban vaping or make it too hard to do, because if smokers can't quit, they should switch to the less harmful habit.

Those safety estimates are just that: nobody knows for sure how dangerous electronic cigarettes really are. Like tobacco products, they contain nicotine. But there is an old saying that nicotine addicts, but tar kills, and there is no carcinogenic tar—a by-product of burning tobacco and paper—in e-cigarettes. It is always possible that e-cigarettes could trigger lung cancer by some currently unknown process, but the disease takes many years to develop, so it is too early to know. Besides, many users combine e-cigarettes with the use of tobacco, thereby complicating the analysis.

Any real danger in e-cigarettes most likely comes from flavorings and other additives, which are big unknowns. Manufacturers use thousands of different chemicals to simulate tastes such as strawberry and cheesecake. It is no wonder that youngsters would be tempted to try them, even before trying regular cigarettes. The new FDA regulations will make it harder for those under 18 to experiment, which is a move in the right direction. Because the rules do not restrict chemical additives, however—which have been ruled safe for eating but not for inhaling—they do not go far enough.

If current assumptions about safety are correct, the risk from e-cigarettes is about on a par with the risk of living with a smoker and inhaling secondhand smoke. That is still significant, and the risk needs to be quantified more precisely: estimates aren't good enough. Unfortunately, that would be prohibitively expensive with current techniques, although emerging testing methods could speed things up over the next several years. In the meantime, however, we cannot ignore the fact that as many as one billion people could be killed by tobacco use during this century. Bringing this number down substantially is an opportunity we cannot miss.

Purists will never be happy with a product that is probably more dangerous than anything we would allow to come to the market in any other industry. They are right. But pragmatic health professionals will see the chance to get many smokers to quit smoking tobacco as a big step in the right direction. They are right, too. My father died from lung cancer caused by cigarettes at the age of 63, after nearly half a century of smoking. If he had switched to e-cigarettes, he might have lived much longer. SA

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Illustration by Errata Carmona

Three hundred black-footed ferrets live in zoos and a captive-breeding program. A few hundred more live in the wild.

BOB ROZINSKI *Getty Images*

CONSERVATION

Genetic Resurrection

To save the black-footed ferret, the U.S. Fish and Wildlife Service hopes to boost the species' genetic diversity—by reinjecting long-gone DNA into the population

In 1987 only 18 black-footed ferrets were known to exist, but thanks to captive breeding and intensive management, the animals are a few hundred strong now. Yet like many species that bounce back from such small numbers, all the individuals are basically half-siblings—genetic near clones, with the same susceptibility to hereditary health problems, to potential pathogens or to environmental changes that could lead to population collapse. In an effort to boost the ferrets' genetic variability and odds of long-term survival, the Fish and Wildlife Service (FWS) is considering something extreme: a plan to reintroduce DNA that was lost to the population but still exists in long-dead specimens stored in zoos and museums. The effort may not sound as outlandish as the dream of resurrecting the woolly mammoth, but it does involve reviving genes that died with their hosts—and as such, it won't be easy.

The black-footed ferret's bottleneck was even worse than it sounds. Of the 18 individuals the FWS rescued nearly 30 years ago from the U.S.'s prairies, only seven passed their genes to subsequent generations. "Every black-footed ferret comes from seven individuals," says Kimberly Fraser, a spokesperson for the FWS's National Black-Footed Ferret Conservation Center. "Take seven humans, and what would we have?"

Last year geneticists funded by the Long Now Foundation's Revive & Restore effort sequenced the genomes of two living ferrets, as well as the DNA of a male and female who died in the 1980s and are stored at the San Diego Zoo's Frozen Zoo. A comparison of the pairs suggests that genetic diversity exists in storage and could be brought back into the living population through, for example, cloning or CRISPR gene editing. This has been explored in attempts to resurrect species

Continued on page 12

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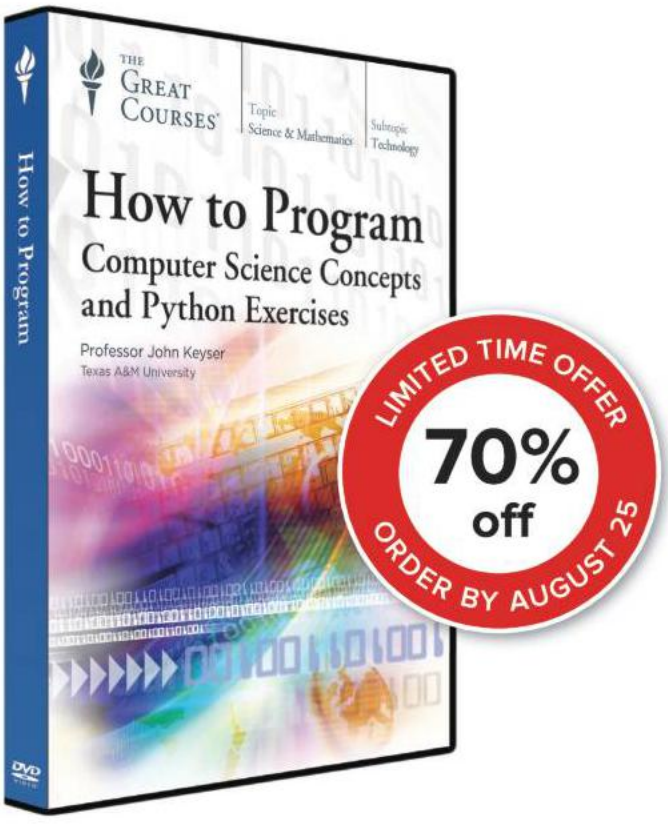

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Continued from page 10

such as the passenger pigeon and could theoretically be used to create clones of the frozen ferrets, which could then be bred with living ferrets. The clones' genomes could also be tweaked to incorporate DNA sequences that code for antibodies to fight two common infections: bubonic plague and canine distemper. Or the genes that make ferrets susceptible to these diseases could be removed. "To have two more genetic founders? That would be a lot," says Ryan Phelan, executive director of Revive & Restore.

The ferret has some advantages in this fight: it is a fast breeder and has close relatives that are thriving and could be used as a surrogate for preliminary cloning research. But it is no surprise that this type of genetic tinkering faces challenges, such as finding adequate funding and facing the legal sticking points that surround genetic projects involving endangered species. Then there are the scientific hurdles, which include the notoriously difficult challenge of creating a viable clone and the long decision-making process about what genes to add or delete. The Revive & Restore group plans to begin the initial gene-editing work this year in cultured cells under the auspices of the Zoological Society of San Diego, assuming funding and researchers can be found.

> Without this genetic restoration effort, inbreeding could push the animals back into decline or even extinction.

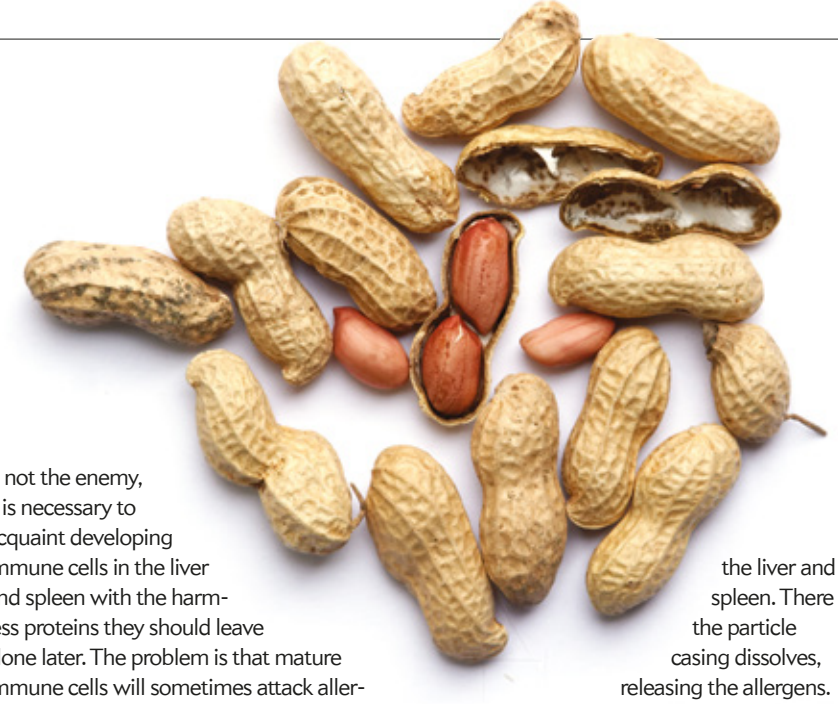
If genetic rescue can help the black-footed ferret thrive, perhaps it can work for other animals and plants that conservationists are trying to save—including amphibians nearly wiped out by chytrid fungus and the inbred Tasmanian devil, which is being ravaged by a contagious facial cancer. In fact, a similar genetic restoration effort is already under way to save the northern white rhino, a subspecies with only three individuals remaining. That attempt will employ the frozen sperm of dead male rhinos as well as "artificial gametes"—stem cells engineered into sex cells that contain restored gene variants. The international team of scientists carrying out the effort recently detailed its plan online in *Zoo Biology,* writing that "[the northern white rhino] can be considered doomed for extinction, unless extraordinary efforts are made to prevent this outcome."

In all such cases, there are ethical considerations. For example, a key argument against de-extinction is that money should not be wasted on resurrecting the mam-

NANOTECHNOLOGY

The New Allergy Shot

Allergens hidden inside nanoparticles make allergy shots safer and more effective



GETTY IMAGES

The first signs of itchy eyes or a runny nose can send allergy sufferers running to the drugstore for over-the-counter relief. Yet these medicines only alleviate allergy symptoms and do nothing to address the root cause: our immune system's overreaction to harmless substances. The sole cure is a series of injections that desensitize the body with small doses of allergens over months or years. But many patients avoid these shots because of possible severe side effects—including anaphylaxis.

That dilemma has led Stephen Miller of Northwestern University and Lonnie Shea of the University of Michigan on a mission to develop a safer method—one that briefly hides the contents of allergy shots from the immune system's attacks.

To teach the immune system what is and is not the enemy, it is necessary to acquaint developing immune cells in the liver and spleen with the harmless proteins they should leave alone later. The problem is that mature immune cells will sometimes attack allergens in an injection before they reach these learning centers. So Miller, an immunologist, and Shea, a biomedical engineer, have designed a Trojan horse delivery method: an allergen enveloped in a nanoparticle. These particles are about the same size as fragments of dying blood cells, so the immune system registers them as normal debris and lets them pass through the bloodstream to the liver and spleen. There the particle casing dissolves, releasing the allergens.

As reported in a new paper in the *Proceedings of the National Academy of Sciences USA,* the researchers tested this idea in mice allergic to ovalbumin, a protein found in eggs. The scientists first loaded nanoparticles with egg proteins, which would trigger a severe allergic reaction on their own, and then injected the nanoparticles into five mice. The mice showed no

moth when there are real elephants to save, and those limited funds could be better spent on protecting habitat or supporting anti-poaching infrastructure. The ferret project, however, would show that the techniques of de-extinction can be applied to real conservation with existing species that are on the brink. As Phelan puts it: "This is a question of at what point do we as stewards help out populations that don't have all the evolutionary adaptability they might have had if things had been different?"

The FWS's ultimate goal is a wild population of 3,000 breeding ferrets spread across 30 different populations, and the service plans to finally restore ferrets to the last place in the wild they were ever found: Meeteetse, Wyo. But without this genetic restoration effort, inbreeding could push the animals back into decline or even extinction. "I don't know that you can spend 100 years in a captive-breeding program and have the limits on genes that we do," FWS's Fraser says. "I hope [genetic rescue] happens before I die." —*David Biello*

reaction. And later, when the researchers injected them with straight ovalbumin to see if they were still allergic, they showed no signs of airway inflammation. Furthermore, blood tests revealed increased numbers of regulatory T cells, which dampen the immune system. These results indicate that the nanoparticle-cloaked allergens slipped through the body's defenses undetected—and that the immune system subsequently learned that these allergens were not the bad guys.

The use of nanoparticles in allergy treatments could offer a powerful tool to combat a range of allergies and even autoimmune disorders such as multiple sclerosis, according to Kari Nadeau, director of the Sean N. Parker Center for Allergy & Asthma Research at Stanford University. That is because the nanoparticle shells can be filled with immune triggers from many different substances, including pollen and dust mites. Other researchers have already seen positive results in experimenting with nanoparticles to treat peanut allergies. Next, Miller and Shea plan to run a clinical trial for celiac disease, a condition in which the immune system overreacts to wheat proteins.

—*Monique Brouillette*

BY THE NUMBERS

$1.4 Billion

That is the amount of money the U.S. spent over a 10-year period from 2004 through 2013 promoting abstinence before marriage as a way of preventing HIV in 14 countries in sub-Saharan Africa. Unfortunately, according to the most comprehensive independent study conducted to date of the effort, the money was more or less wasted. A rigorous comparison of national data from countries that received abstinence funding under the U.S. President's Emergency Plan for AIDS Relief (PEPFAR) with those that got none of the funding showed no difference in the age of first sexual experience or in the number of sexual partners or teenage pregnancies—all aspects of behaviors that have been linked to a higher risk of becoming infected with HIV.

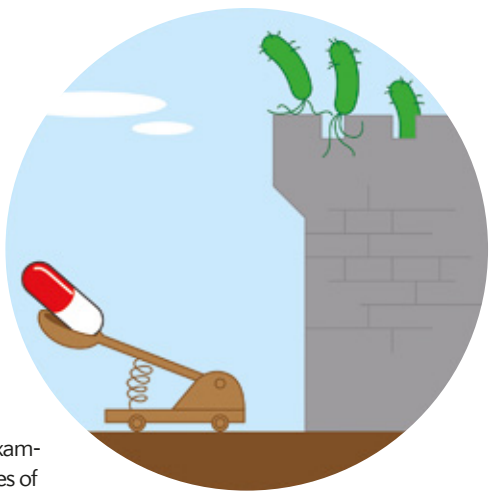
Instead the study showed that one of the most important factors associated with lower levels of risky behavior was the number of years women remained in school. Other efforts that have proved effective in slowing the spread of HIV include treating the infection in pregnant women so they do not pass the virus on to their newborns, the study added. The research by Nathan Lo, Anita Lowe and Eran Bendavid, all at the Stanford University School of Medicine, was published in the May *Health Affairs*.

Although the latest findings about PEPFAR's prevention efforts are disappointing, its treatment programs have been entirely more successful. A previous study by Bendavid in 2009 and another in 2012 showed that the government initiative has saved at least a million lives by making anti-HIV medications more widely available to those who need them. —*Christine Gorman*

HEALTH

Divide and Conquer

Severing the sugars that bind communal bacteria together could make antibiotics more effective



Bacteria are sticky—so sticky that we schedule regular appointments with professionals to scrape them off our teeth. Dental plaque may be the best-known example of a biofilm, but these slimy aggregates of bacteria also play major roles in such chronic infections as those in the urinary tract or in the lungs in cystic fibrosis patients. The problem? Antibiotics often can't penetrate the slime to get at (and destroy) the pathogenic bacteria cocooned within.

To build a biofilm, bacteria secrete stringy sugars, proteins and DNA fragments into what effectively becomes a defensive mesh around the microorganisms—making the structures the microbial world's equivalent of "walled cities," according to structural biologist Perrin Baker of Toronto's Hospital for Sick Children. He and his colleague Lynne Howell have been working on methods to dismantle these structures. "What we want to do is create chinks in the wall to allow the invading army in," Howell explains.

To make these cracks, the researchers turned to *Pseudomonas aeruginosa*—a bacterial species that often builds biofilms within the lungs of cystic fibrosis patients, which can lead to chronic obstructive pulmonary disease and subsequently death. *P. aeruginosa* produces several different enzymes that can clear away overgrown or tangled biofilm sugars so the bacteria can navigate the structure themselves. Baker and Howell wanted to see if they could turn these enzymes to their advantage.

Illustrations by Thomas Fuchs

NEUROSCIENCE

Your Brain on Physics

The brain repurposes everyday neural networks to learn science

Early *Homo sapiens* wasn't acquainted with Einstein's general theory of relativity, yet anyone in a physics class today is expected to understand its basic tenets. "How is it that our ancient brains can learn new sciences and represent abstract concepts?" asks Marcel Just, a neuroscientist at Carnegie Mellon University. In a study published in June in *Psychological Science,* Just and his colleague Robert Mason found that thinking about physics prompts common brain-activation patterns and that these patterns are everyday neural capabilities—used for processing rhythm and sentence structure, for example—that were repurposed for learning abstract science.

Just and Mason scanned the brains of nine advanced physics and engineering students as they thought through 30 physics concepts such as momentum, entropy and electric current. The researchers fed the data from the scans into a machine-learning computer program, which eventually could identify which concept a volunteer was thinking about based on his or her brain activity. Why was this possible? Because the neural patterns involved in considering a particular topic—gravity, for instance—were the same in all participants. "Everyone learns physics in different classrooms, with different teachers, at different rates," Mason says. "So it's surprising that the same brain regions are developed for understanding a physics concept in all these students."

To take it further, the scientists then compared the scans from their study with previous research matching neural activity to thought processes. They found that brain responses corresponding to the scientific concepts of "frequency" or "wavelength" occurred in the same regions that activate when people watch dancers, listen to music or hear rhythmic patterns such as a horse's gallop—likely because these all involve sensing "periodicity." And when the students thought through mathematical equations, the engaged brain areas were the same as those that process sentences. These results suggest that general neural structures are repurposed for dealing with high-level science.

"So even though some of these concepts have only been formalized in the past couple of centuries, our brains are already built to deal with them," Just says.

The findings may someday help determine which school lessons should be taught together for easiest consumption, Mason says. He and Just plan on continuing their work with other sciences our ancestors knew little about, including genetics and computer science. —*Jordana Cepelewicz*

They first extracted two biofilm-pruning enzymes from the microbes and then added them to petri dishes coated with biofilms. As recently reported in *Science Advances,* the researchers found that the enzymes destroyed most of the sugary infrastructure built by several different *Pseudomonas* strains. With one strain, for example, 94 percent of the biofilm's mass dissolved on contact with the enzymes.

Even though the enzymes tear down large sections of the biofilms, the bacteria within are left unharmed. So the method "wouldn't be a magic bullet" on its own, says Stanford University infectious disease expert Paul Bollyky, who was not involved in the study. Yet it does leave the vast majority of bacterial residents exposed and therefore vulnerable to a follow-up round of antibiotics or the natural attacks of the body's immune system.

The researchers will next try to find out whether the enzymes are as successful at combating biofilms in the lungs of mice as they are in petri dishes. Baker is also interested in seeing if coating hospital equipment with sugar-cutting enzymes could help prevent the formation of drug-resistant germs.

—*Diana Crow*

LOGISTICS

Model Airplane

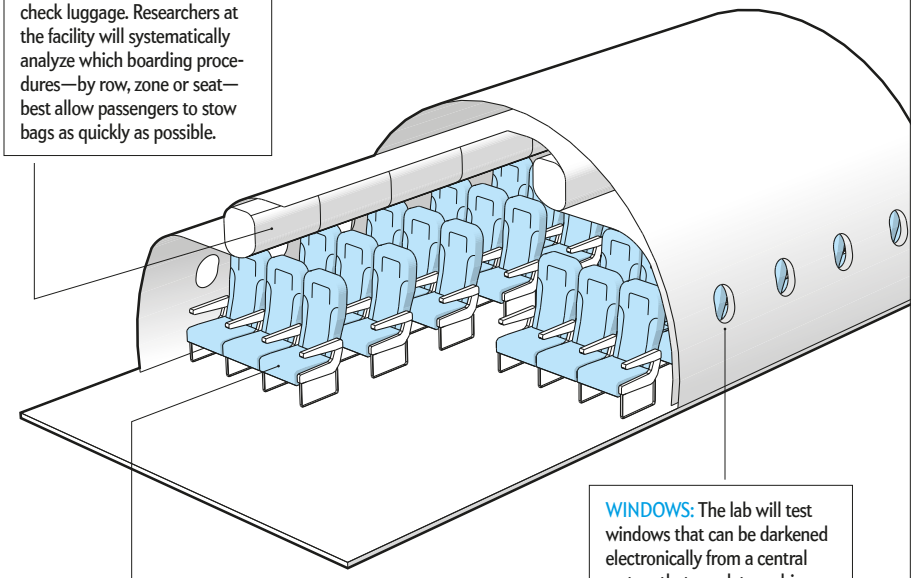
A new lab will simulate air travel from start to finish to determine the future of cabin design

A commercial flight is no place to run experiments—at least with any scientific rigor. Airplane manufacturers and airlines alike want to try out new cabin designs, seating arrangements and boarding procedures, but testing those ideas on actual passengers at 40,000 feet is prohibitively expensive, potentially dangerous and impossible to control. The National Research Council of Canada is now building a facility in Ottawa that re-creates several aspects of air travel, with a reconfigurable cabin that can faithfully simulate hours-long plane trips. According to Paul Lebbin, project manager for the new Cabin Comfort and Environment Research facility, the studies conducted at the laboratory will "help airlines balance profitability with what the passengers want." Construction is scheduled to begin this summer, and several experiments are already on the docket. *—Jennifer Hackett*

CABIN: The lab's cabin is entirely modular—its seats, windows and storage compartments can all be detached and reconfigured to re-create conditions onboard many types of passenger planes. As such, tests can cater to specific jet models. In-flight noise levels, lighting, air pressure, humidity and airflow can all be simulated.

AIRFLOW: The way air is circulated through most cabins has not changed since the 1980s: air from the engine's compressors is adjusted for temperature, mixed with recycled and filtered air, and then pumped into the cabin above passengers. The system is noisy and energy-intensive and distributes fresh air unevenly. The lab will test new ways to deliver oxygen-rich air from the floor instead—a setup that reduces strong pumping and therefore uses less energy and is quieter.

LUGGAGE: Passengers are increasingly traveling with large carry-on bags because of fees to check luggage. Researchers at the facility will systematically analyze which boarding procedures—by row, zone or seat—best allow passengers to stow bags as quickly as possible.



WINDOWS: The lab will test windows that can be darkened electronically from a central system that regulates cabin lighting and temperature levels. These glass "microblinds" could also reduce an aircraft's weight and therefore lower fuel costs.

SEATS: The constant vibration crew members experience during flight can lead to fatigue, neck strain and other health problems. Researchers will compare how well different types of seat cushions dampen vibrations by placing a row of seats on a massive shake table and then measuring the vital signs of people sitting in them.

NEUROSCIENCE

Can We Learn How to Forget?

Neuroscientists begin to understand how the brain controls its own memory center

After reflexively reaching out to grab a hot pan falling from the stove, you may be able to withdraw your hand at the very last moment to avoid getting burned. That is because the brain's executive control can step in to break a chain of automatic commands. Several new lines of evidence suggest that the same may be true when it comes to the reflex of recollection—and that the brain can halt the spontaneous retrieval of potentially painful memories.

Within the brain, memories sit in a web of interconnected information. As a result, one memory can trigger another, making it bubble up to the surface without any conscious effort. "When you get a reminder, the mind's automatic response is to do you a favor by trying to deliver the thing that's associated with it," says Michael Anderson, a neuroscientist at the University of Cambridge. "But sometimes we are reminded of things we would rather not think about."

Humans are not helpless against this process, however. Previous imaging studies suggest that the brain's frontal areas can dampen the activity of the hippocampus, a crucial structure for memory, and therefore suppress

Illustration by Jason Lee

The results may explain why some people who have experienced trauma have poor memory of everyday events.

retrieval. In an effort to learn more, Anderson and his colleagues recently investigated what happens after the hippocampus is suppressed. They asked 381 college students to learn pairs of loosely related words. Later, the students were shown one word and asked to recall the other—or to do the opposite and to actively *not* think about the other word. Sometimes between these tasks they were shown unusual images, such as a peacock standing in a parking lot.

As described in *Nature Communications,* the researchers found that the participants' ability to subsequently recall the peacocks and other strange pictures was about 40 percent lower if they had been instructed to suppress memories of words before or after seeing the images, compared with trials in which they had been asked to recall the words. The finding provides further evidence that a memory-control mechanism exists and suggests that trying to actively forget a particular memory can negatively affect general memory. The researchers call the phenomenon an "amnesic shadow" because it apparently blocks recollection of unrelated events happening around the time of decreased hippocampal activity. The results may explain why some people who have experienced trauma (and then tried to forget it) have poor memory of everyday events, say experts not involved in the study.

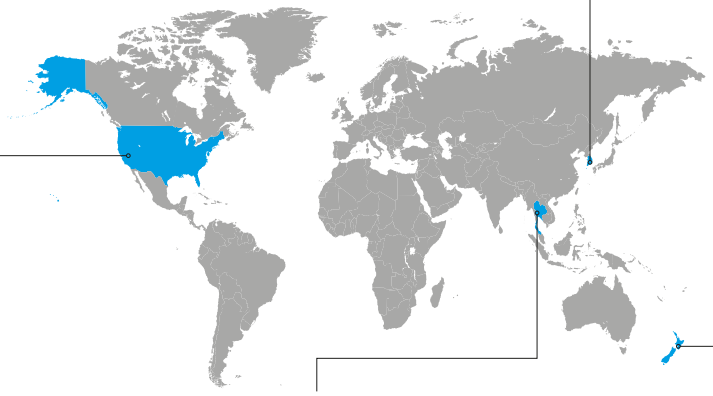
Minus the temporary amnesia, suppressing memories on demand could be a useful skill, Anderson says. That is why he and his colleague Ana Catarino are now studying whether it is possible to train people in the art of suppression: they are currently conducting an experiment in which they monitor participants' brain activity in real time and provide verbal feedback about how much hippocampal activity is dampened. They hypothesize that the cues could help someone learn how to become better at selectively forgetting the past—an ability that could especially ameliorate the pain of those with post-traumatic stress disorder. —*Bahar Gholipour*

IN THE NEWS

Quick Hits

NORTHWEST PASSAGE
This month a cruise ship with 1,000 passengers is scheduled to traverse the once iced-in Arctic sea route that connects the Pacific and Atlantic oceans. The ship will depart from Seward, Alaska, and arrive in New York City 32 days later.

SOUTH KOREA
Pregnant women in Busan, South Korea's second-largest city, can now carry a small device that wirelessly signals a pink light to turn on above priority seats in subway cars and buses. The light indicates to other passengers that the seat is needed.



U.S.
Skiers can still hit the slopes this month near Lake Tahoe, Calif. A resort there is the first in the country to use a "snow factory," a machine that can make snow in temperatures up to 80 degrees Fahrenheit. Traditional snow cannons can generate flakes only below 28 degrees F.

NEW ZEALAND
Geologists discovered a massive chamber of molten rock below an area that has no volcanoes. The unusual accumulation of magma could explain a series of recent earthquakes or signal the development of a new volcano. An eruption is not imminent, experts say.

THAILAND
Local authorities removed 137 tigers from a Buddhist monastery in western Thailand, citing evidence of wildlife trafficking. The controversial "Tiger Temple" has long attracted tourists, who were charged up to $140 for snapshots with the big cats.

For more details, visit
www.ScientificAmerican.com/aug2016/advances

GLOBAL HEALTH

Zika-Proofing the Olympics

From mosquito-repelling uniforms to specially treated condoms, several Olympic teams are taking extra measures to avoid infection

The Brazilian Ministry of Health estimates that there were nearly 150,000 new cases of Zika virus infection in Brazil in the first half of 2016. Those numbers have made athletes, fans and many others nervous about traveling to Rio de Janeiro for this month's Summer Olympics. Although the virus is relatively harmless to most people—three out of four of those infected are asymptomatic—it can cause severe birth defects if it strikes a pregnant woman.

But infectious disease experts say panic over Zika, which is largely transmitted by mosquitoes, is unwarranted. "For most people, and women who are not pregnant, it's going to be relatively safe to go to Rio," says Ashish K. Jha, director of the Harvard Global Health Institute. "There are certainly standard precautions that people should be taking if they're traveling there as an athlete or as a spectator. But if people do a good job of being cautious and using insect repellents, I don't think there's any evidence that additional measures are particularly necessary or even useful."

Similarly, the World Health Organization and the International Olympic Committee have said that the risk of getting Zika at the Olympics is relatively low. And most epidemiologists and infectious disease experts agree that there is no need to postpone the games in light of new disease-transmission models and a better understanding of mosquito activity in August (it will be lower). Of course, that has not stopped individual teams from taking extra precautions to prevent the spread of the virus among their athletes.

—Knvul Sheikh

GETTY IMAGES

CANADA Screens will be installed on bedroom windows at the Canada Olympic House to keep out mosquitoes. Other Olympic teams also have the option to pay for this upgrade.

SOUTH KOREA The country's athletes will be wearing long pants and long-sleeved shirts and jackets, both infused with mosquito-repellent chemicals. The "Zika-proof" uniforms will be worn during the ceremonies and training and at the Olympic Village.

U.S. Among other Zika-prevention measures, the U.S. Olympic committee will provide its athletes with unlimited bottles of OFF! insect repellent.

AUSTRALIA Condoms coated with an antiviral lubricant will be distributed to all Australian athletes to protect against sexual transmission of the virus. The condoms have been approved in Australia for HIV, herpes simplex and human papillomavirus.

In plant cells, chloroplasts carry out photosynthesis.

ED RESCHKE *Getty Images*

TECHNOLOGY

Bionic Is Better

At least when it comes to performing photosynthesis

A tree's leaf, a blade of grass, a single algal cell: all make fuel from the simple combination of water, sunlight and carbon dioxide through photosynthesis. Now scientists say they have replicated—and improved on—that trick with their own "bionic leaf."

Chemist Daniel Nocera of Harvard University and his team joined forces with synthetic biologist Pamela Silver of Harvard Medical School and her team to craft a kind of living battery, which they call a bionic leaf for its melding of biology and technology. The device uses solar electricity from a photovoltaic panel to power the chemistry that splits water into oxygen and hydrogen. Microbes within the system then feed on the hydrogen and convert carbon dioxide in the air into alcohol that can be burned as fuel. The team's first artificial photosynthesis device appeared in 2015—pumping out 216 milligrams of alcohol fuel per liter of water—but the nickel-molybdenum-zinc catalyst that made its water-splitting chemistry possible had the unfortunate side effect of poisoning the microbes.

So the team set out in search of a better catalyst and, as recently reported in *Science,* the researchers found it in an alloy of cobalt and phosphorus, an amalgam already in use as an anticorrosion coating for plastic and metal parts. With this new catalyst in the bionic leaf, the team boosted version 2.0's efficiency at producing alcohol fuels such as isopropanol and isobutanol to roughly 10 percent. In other words, for every kilowatt-hour of electricity, the microbes could scrub 130 grams of CO_2 out of the air to make 60 grams of isopropanol fuel. Such a conversion is roughly 10 times more efficient than natural photosynthesis.

Nocera says that by knitting fuels out of the excess CO_2 in the air, this new bioreactor technology could help mitigate planet-warming pollution problems while bringing cleaner fuels to people who lack access to modern energy.

—David Biello

MIKE POWLES Getty Images

EVOLUTION

Toothless Beaks for the Win

Did the ancestors of modern birds survive because they ate seeds?

Sixty-six million years ago an asteroid struck Earth and wiped out an estimated 75 percent of life. It is an event that infamously caused the extinction of the dinosaurs, which leads one to wonder: How did the ancestors of modern-day birds survive when all their relatives perished? A new study published in *Current Biology* hypothesizes that some birdlike dinosaurs lived because they had toothless beaks and could subsist off fire-resistant seeds when the food sources of most other species disappeared.

Derek Larson, assistant curator at the Philip J. Currie Dinosaur Museum in Alberta, and his colleagues first analyzed more than 3,000 fossilized teeth from birdlike dinosaurs that lived in western North America during the Cretaceous period. Based on size and shape, the researchers concluded that these teeth were suited for eating animals, insects and plants and had remained largely unchanged for the 18 million years leading up to the mass extinction.

Because the avian fossil record is incomplete, the team then reconstructed the eating habits of the ancestors of modern birds with the help of a statistical model of evolution. It indicated their toothless ancestors probably lived off seeds. Together these analyses suggest that the difference between life and death for various birdlike dinosaurs came down to a combination of dentition and diet.

In support of this hypothesis, Larson also cites a body of research on modern wildfires. These studies show that some seeds remain unharmed despite scorching and that seed-eating birds are among the first species to return to a burned forest—analogous to Earth's surface after the Chicxulub impact.

Larson's approach to figuring out how animals survived 66 million years ago is a valuable and creative one, says Julia A. Clarke, a vertebrate paleontologist at the University of Texas at Austin who was not involved in the study. But she notes that extinction dynamics are complex, and evidence from bird fossils in other parts of the world tells a different story. "I just got back from two months in Antarctica working on fossils from the late Cretaceous, and what we see is that the species there were aquatic. Based on our comparison with living birds, they presumably ate algae and fish," she explains.

In addition, research indicates that early relatives of ostriches, emus and ducks from the late Cretaceous were toothless but likely would have eaten small vertebrates and insects in addition to seeds, Clarke adds. "I would be surprised if seed eating was the only trait linked to survivorship or extinction." —*David Godkin*

SUSTAINABILITY

Waste Not, Want Not

The first comprehensive global look at food waste is as bad as you'd expect

From produce that rots in delivery trucks to oversized portions on restaurant plates, we waste vast amounts of food. In fact, researchers at the Potsdam Institute for Climate Impact Research in Germany recently found that the average amount of food wasted per person per day has increased from 310 kilocalories in 1965 to 510 kilocalories in 2010. That is roughly the equivalent of going from dumping six apples in the trash to tossing 10 of them—every single day. By 2050 that number could go as high as 850 kilocalories, the researchers predict.

An exact tally of food waste is impossible, so to calculate these numbers the Potsdam team used a proxy: food surplus, or the difference between the amount of food a country produces or imports for consumption and the total calories its populace requires. They ran the numbers for 169 countries (98 percent of the world's population) and calculated that in 2010—the year with the most recent data available—20 percent more food was available globally than what the human population needed. Overall, the higher a country's standard of living, the more food it wasted. The results were published in *Environmental Science & Technology*.

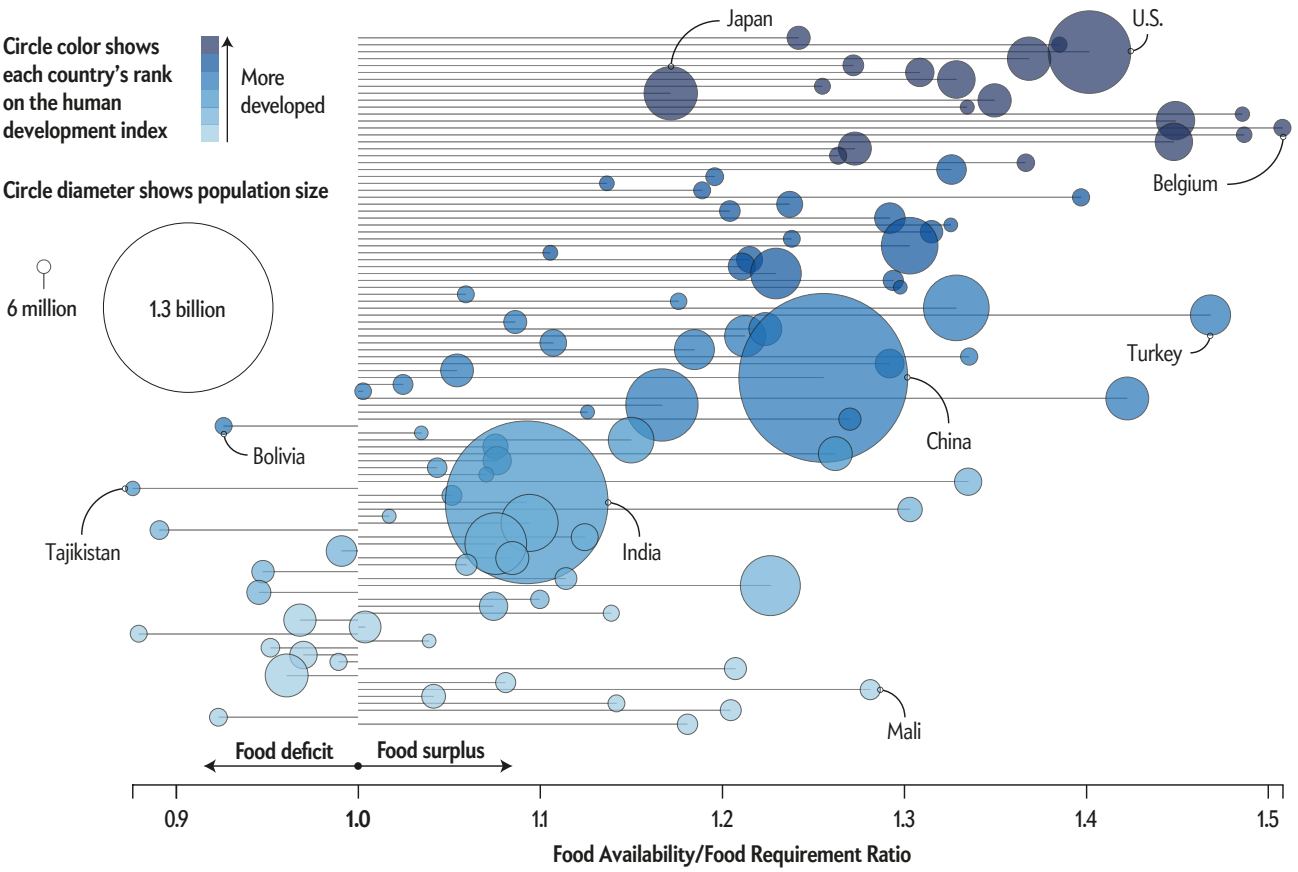
Is all that extra food literally going into the garbage? Not necessarily, says co-author and geoecologist Prajal Pradhan. People often eat more than they require (a complex and subjective calculation in its own right), and some leftovers also become livestock feed. That means the study probably overestimated food waste, although Pradhan says the study incorporated fluctuating body weight data that should at least partly compensate for many of the people who simply overeat.

This overestimation does not weaken Pradhan's findings, however, says Matti Kummu, a civil and environmental engineering professor at Aalto University in Finland who was not involved in the study. "Food surplus might be a simplistic estimate of food waste, but it's a good one."

There is also a silver lining to this surplus situation: if we could slash food waste, we could feed the world's projected population of at least nine billion people in 2050 without heroic increases in agricultural productivity. —*Prachi Patel*

Wasting Food Is Common Practice the World Over

Each circle represents a country. Horizontal position shows the size of each country's food surplus (*lines extending to right*) or deficit (*lines extending to left*). The countries shown are among the 100 most populous.



SOURCE: "FOOD SURPLUS AND ITS CLIMATE BURDENS," BY CEREN HIÇ ET AL., IN *ENVIRONMENTAL SCIENCE & TECHNOLOGY*, VOL. 50, NO. 8, APRIL 19, 2016

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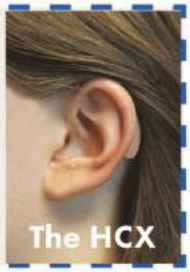

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Jeneen Interlandi is a New York City–based journalist who writes about health, science and the environment.

The Acupuncture Myth

Scientific studies show that the procedure is full of holes

By Jeneen Interlandi

In 1971 then *New York Times* columnist James Reston had his appendix removed at a hospital in China. The article he wrote about his experience still reverberates today. His doctors used a standard set of injectable drugs—lidocaine and benzocaine—to anesthetize him before surgery, he explained. But they controlled his postoperative pain with something quite different: a Chinese medical practice known as acupuncture, which involved sticking tiny needles into his skin at very specific locations and gently twisting them. According to Reston, it worked.

Readers back home were fascinated. In a rush of excitement over this new, exotic knowledge, the original story was quickly jumbled. Before long, it was commonly believed that the Chinese doctors had used acupuncture not just after Reston's appendectomy but as anesthesia for the surgery itself. Interest in acupuncture soared in the U.S. and has remained high ever since.

But it turned out that acupuncture as Reston described it was not the enduring bit of ancient Chinese wisdom enthusiasts supposed. In fact, the procedure had been written off as superstition back in the 1600s and abandoned altogether in favor of a more science-based approach to healing by the 1800s. Chinese Communist Party leader Mao Zedong had only revived acupuncture in the 1950s as part of his initiative to convince the Chinese people that their government had a plan for keeping them healthy despite a woeful dearth of financial and medical resources.

Even more impressive than how well Mao's campaign worked in China at the time is how well it is working in the U.S. today. Every year hundreds of thousands of Americans undergo acupuncture for conditions ranging from pain to post-traumatic stress disorder, and the federal government spends tens of millions of dollars to study the protocol.

So far that research has been disappointing. Studies have found no meaningful difference between acupuncture and a wide range of sham treatments. Whether investigators penetrate the skin or not, use needles or toothpicks, target the particular locations on the body cited by acupuncturists or random ones, the same proportion of patients experience more or less the same degree of pain relief (the most common condition for which acupuncture is administered and the most well researched). "We have no evidence that [acupuncture] is anything more than theatrical placebo," says Harriet Hall, a retired family physician and U.S. Air Force flight surgeon who has studied, and long been a critic of, alternative medicine.

But the news is not all bad. In the process of putting acupuncture to the test, scientists have gained insights that could lead to the development of new and urgently needed methods for treating pain.

SMALL EFFECTS

ACUPUNCTURE IS BASED ON the concept of qi (pronounced "chi"), a life force or energy that practitioners say flows through the body along 20 distinct routes called meridians. Blocked meridians are believed to cause illness by disrupting the flow of qi. Inserting acupuncture needles at specific points along specific meridians is thought to clear those blockages and restore qi's natural flow, which in turn restores patients to health. Scientists have long understood that qi is not a legitimate biological entity; many studies have shown that the effects of acupuncture are the same whether needles are placed along the meridians or at random locations around the body. But the acupuncture proponents among them have argued that acupuncture itself might still work, albeit by an as yet unknown mechanism.

Some of the best support for this contention came in 2012, when researchers at Memorial Sloan Kettering Cancer Center and their colleagues published a meta-analysis of 29 studies involving nearly 18,000 patients, which found that traditional acupuncture produced a somewhat greater reduction in pain than placebo or sham acupuncture. The finding was widely touted as the first clear proof that acupuncture actually works. But critics have dismantled that interpretation. For one thing, they point out, acupuncture studies are extremely difficult to double-blind—a methodological approach in which neither the re-

Illustration by Eric Diotte

searchers nor patients know who is receiving the treatment under investigation and who is receiving the placebo or sham. The researchers knew which patients were and were not getting real acupuncture, and that awareness almost certainly biased their results. In addition, although statisticians detected a difference in pain relief between treatment and placebo, the effect may have been lost on patients. "What [the study authors] are arguing is that a change of 5 on a 0–100 pain scale … is noticeable by patients," David Gorski, a surgical oncologist at the Wayne State University School of Medicine, observed in a blog post. "It's probably not."

The lack of scientific support for acupuncture has not curbed enthusiasm for the practice. Blue-chip medical centers such as the Mayo Clinic and Massachusetts General Hospital now have dedicated acupuncturists on staff. Health insurance programs are starting to cover acupuncture to a limited extent, and individual consumers who cannot get insurance to foot the bill are collectively shelling out millions from their own pockets. Nor have the findings stopped the flow of government money into acupuncture programs, which has totaled more than $73 million since 2008. In that time, Mass General has received $26 million in such funding from the Department of Health and Human Services, largely for studies that scan the brains of people being treated with acupuncture or thinking about being treated with acupuncture. And the Department of Defense has awarded more than $12 million in acupuncture contracts and grants.

Part of that continued investment could have to do with patient demand. But there are other justifications. Josephine Briggs, director of the National Center for Complementary and Integrative Health (the NIH division responsible for all alternative medicine research), acknowledges that the balance of evidence points to a placebo effect for acupuncture. Yet in her view, there is still good reason to study the procedure. "It isn't implausible that the effect of a lot of needles may change central pain processing in some concrete way," she says. Just as the finding that tea made from willow bark could alleviate headaches led scientists to the discovery of salicylic acid—which in turn led to the invention of aspirin—many acupuncture researchers think that their work might lead to a treatment for pain that is more effective than acupuncture. Their goal, in other words, is not to justify acupuncture per se but to find out if a mechanism of some kind can explain those very small effects and, if so, whether that mechanism can be exploited to produce a viable treatment for pain.

A POSSIBLE MECHANISM

WITH THIS GOAL IN MIND, scientists have been studying a roster of potential biological pathways by which needling might relieve pain. The most successful of these efforts has centered on adenosine, a chemical believed to ease pain by reducing inflammation. A 2010 mouse study found that acupuncture needles triggered a release of adenosine from the surrounding cells into the extracellular fluid that diminished the amount of pain the rodents experienced. The mice had been injected with a chemical that made them especially sensitive to heat and touch. The researchers reported a 24-fold increase in adenosine concentration in the blood of the animals after acupuncture, which corresponded to a two-thirds reduction in discomfort, as revealed by how quickly they recoiled from heat and touch. Injecting the mice with compounds similar to adenosine had the same effect as acupuncture needling. And injecting compounds that slowed the removal of adenosine from the body boosted the effects of acupuncture by making more adenosine available to the surrounding tissue for longer periods. Two years later a different group of researchers went on to show that an injection of PAP, an enzyme that breaks other compounds in the body down into adenosine, could relieve pain for an extended chunk of time by increasing the amount of adenosine in the surrounding tissue. They dubbed that experimental procedure "PAPupuncture."

Both sets of findings have excited researchers—and for good reason. The current options for treating pain are limited and rely mostly on manipulating the body's natural pain-management system, known as the opioid system. Opioid-based painkillers are problematic for several reasons. Not only does their efficacy tend to wane over time, but they have been linked to an epidemic of addiction and overdose deaths across the U.S.—so much so that the Centers for Disease Control and Prevention has recently advised doctors to seriously restrict their use. The available nonopioid pain treatments are few; many of them require multiple injections or catheterization to work; and they often come with side effects, such as impaired movement. Adenosine offers an entirely new mechanism to exploit for potential treatments—one that may come with fewer side effects and less potential for addiction. What is more, adenosine can be made to circulate in the body for prolonged stretches. Pharmaceutical companies are actively investigating adenosine-related compounds as potential drugs.

But however promising adenosine may be as a treatment, the findings from this research do not prove that acupuncture itself "works." For one thing, the researchers did not show that the release of adenosine was specific to acupuncture. Acupuncture needles might cause adenosine to flood the surrounding tissue, but so might a hard pinch, or applied pressure, or any number of other physical insults. In fact, both of the studies found that when adenosine was turned on in mouse tissue by other mechanisms, the pain response was equal to or better than the response generated by acupuncture. For another thing, the study results offered no support for the use of acupuncture to treat any of the other conditions for which the procedure is often advertised. A localized adenosine response may mitigate localized pain. That does not mean it can also cure insomnia or infertility.

It may well be that the reams of research scientists have done on acupuncture have lit the path toward improved understanding of—and eventually better treatments for—intractable pain. But it may also be time to take whatever bread crumbs have been laid out by that work and move on. SA

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

The End of Passwords

They're on the way out, and it's about time

By David Pogue

Our tech lives are full of pain points, but at least the world's tech geniuses seem committed to solving them. Today who complains about the things that bugged us a decade ago, such as heavy laptops, slow cellular Internet, the inability to do e-mail in planes?

It was only a matter of time before those geniuses started tackling one of the longest-running pain points in history: passwords. We're supposed to create a long, complex, unguessable password—capital and lowercase letters, numbers and symbols, with a few Arabic letters thrown in if possible. *For each site.* Don't reuse a password. Oh, and change them all every month.

Sorry, security experts. Not possible. Not for an average person, not even for you. Nobody has that kind of memory.

To make matters worse, passwords aren't even especially secure. See any recent headline about stolen passwords or about some company's servers being hacked.

It's time to kill the password.

Surely, in the 50 years since we started typing passwords, somebody must have invented a better security system. The answer: yes and no. Apps such as 1Password and Dashlane memorize and enter long, complicated passwords *for* you. But most of them cost money, they don't work on every Web account and the nontechie public doesn't know they exist.

There's also two-factor authentication, which makes you type a password *and* a code texted to your phone to log in. It's an unbelievable hassle. The masses will never go for it.

Finally, biometric approaches can be both secure and easy because they recognize *us,* not memorized strings of text. Here there's hope. Fingerprint readers on smartphones, tablets and laptops are becoming common, cheap, convenient and essentially impossible to hack on a large scale. So far they're primarily useful for logging us into our *machines.* Shouldn't the next step be letting us log into our Web accounts? Iris scanning is another biometric technology, fast enough to work well at automated border-crossing systems and secure enough for national ID programs such as India's (it's enrolling 1.2 billion people).

At the moment, iris scanners are far too new and expensive to build into every phone and laptop—but almost every technology gets cheaper over time. Some scanners can be fooled by a photograph of your eye, but this problem, too, can be overcome (by tracking your pupil as you read something, for example). Bottom line: there's no insurmountable problem in iris reading's future.

Same with voice authentication, using the unique pitch, accent and frequencies of your speaking voice as your key. It's cheap enough for wide adoption—our phones and gadgets already have microphones. Worried about bad guys faking out the system with a recording of your voice? That can't happen if the phrase you're asked to speak changes every time you log in.

The only roadblocks here are background noise and laryngitis. And as with any biometric security solution, this approach really requires a backup system—like a password—just in case.

Then there's Windows Hello, a new feature of Windows 10 that lets you log in with fingerprint, iris or facial recognition—whatever your laptop is equipped to handle. The face option is especially exciting. You just sit down at the computer, and it unlocks instantly. You can't fool it with a photograph or even a 3-D model of your head, because the Intel RealSense camera it requires includes infrared and 3-D sensors.

Of course, very few gadgets come with that camera preinstalled. But the RealSense concept is truly the Holy Grail: secure and convenient. If the hardware ever became as ubiquitous and cheap as, say, our phones' fingerprint readers, we could have a winner.

Clearly, the password concept is broken. Equally clearly, these new technologies can provide both the security and the convenience the world demands. Nothing's quite there yet, and we need to keep our eye on privacy concerns (who owns the databases of biometric scans, for example?).

But one thing is for sure: this is one pain point that's got everyone's attention. SA

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Illustration by Thomas Fuchs

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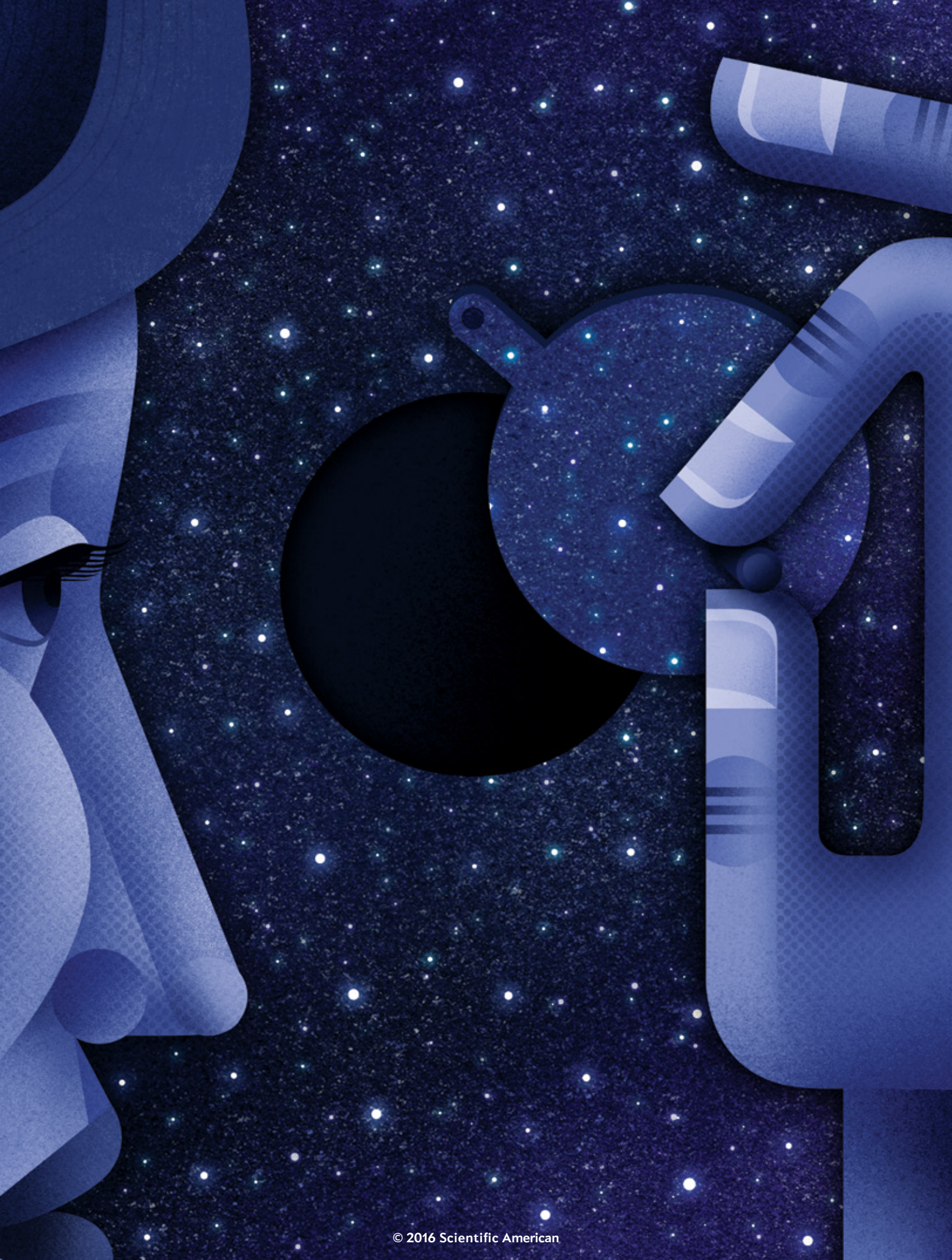
COSMOLOGY

THE EMPTIEST PLACE IN SPACE

Efforts to explain a strange cold spot in the cosmos have led to the discovery of something even odder: ***a vast area with very little matter***

By István Szapudi

Illustration by Maria Corte Maidagan



István Szapudi is an astronomer at the University of Hawaii's Institute for Astronomy who studies cosmology and the large-scale structure of the universe.

TO GLIMPSE THE OLDEST LIGHT IN THE UNIVERSE, SIMPLY TUNE AN OLD TELEVISION between channels: the tiny specs dancing on the screen result from the antenna being bombarded relentlessly by photons that were emitted shortly after the big bang, some 13.8 billion years ago. These photons fly uniformly through space from all directions, with an average temperature of 2.7 kelvins (–455 degrees Fahrenheit), composing a cloud of radiation called the cosmic microwave background (CMB). Because these photons are so old, the familiar two-dimensional map of the CMB is often called a "baby picture" of the universe, providing a window back into the primordial conditions that created the cosmos we see around us today.

Our baby picture, however, has a few imperfections. Physicists like myself call them anomalies because they cannot be fully explained by our standard cosmological theories. The largest of these anomalies, first found in NASA's Wilkinson Microwave Anisotropy Probe (WMAP) map of the CMB in 2004, is the "cold spot," an area of the sky covering about 20 times the width of the full moon, where the ancient photons are unusually chilly. The cold spot is not unlike a beauty mark on our baby picture: for some, it is an ugly mole that breaks the majestic symmetry of the CMB; for others, it enhances the features of the universe and adds to the excitement. I am in the latter camp: I have always been fascinated with this CMB anomaly and what might account for it.

That puzzle has stimulated much discussion among scientists. One explanation might be that it arose by sheer chance, with no specific cause. But the odds of chance being the cause are low: about one in 200. Other possibilities range from the mundane to the fantastic—from problems with the instruments analyzing the cosmos to the suggestion that the cold region is a portal to another universe or hidden dimensions.

In 2007, by extrapolating from some known features of the cosmos, I and other astrophysicists hit on the idea that just such a cold spot might be expected to form if the cosmos contained a supervoid—a vast expanse of space relatively devoid of matter and galaxies—in the same region of the sky. This void would be the emptiest place in space, a rare gigantic wasteland amid relatively dense surroundings. The theory had enormous implications. If such a void did indeed exist and cause the cold spot in the way we imagined, the huge empty region might, for complex reasons, also provide proof for dark energy, the theorized culprit behind the accelerating expansion of the universe. Today my colleagues and I at the University of Hawaii have confirmed the void, and we are finding tantalizing clues that it could indeed account for the cold spot.

CROSSING THROUGH A VOID

SCIENTISTS CAME TO THE IDEA that a supervoid might exist and give rise to the cold spot by contemplating the way we think light interacts with smaller voids. The postulated supervoid would be extreme, but regular midsize voids—areas containing

IN BRIEF

The cosmic microwave background (CMB), the ancient light that pervades the universe, shows an odd "cold spot" where its photons are significantly cooler than average.

One possible explanation is a theorized giant supervoid—a vast region of relatively empty space in the same region of the sky as the cold spot. Light traveling through a supervoid would tend to lose energy (become colder) because of what is called the integrated Sachs-Wolfe (ISW) effect produced by the accelerating expansion of the universe.

Astronomers recently discovered a supervoid extending 1.8 billion light-years across aligned with the cold spot. More data are necessary to determine for sure if it is responsible for the CMB's chilly zone.

SCANS OF THE SKY by the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) on Maui helped astronomers identify an immense expanse of relatively empty space—a "supervoid"—that may explain an enigmatic cold spot in the universe's oldest light.

relatively few galaxies—are common in the universe. So are their opposites, clusters, which are large conglomerations of up to thousands of galaxies. Cosmologists think that the seeds of voids and clusters arose in the very early universe, when random quantum-mechanical processes caused matter to be slightly less dense in some parts of space and slightly more dense in others. The greater mass in the overdense regions wielded a stronger gravitational pull that drew more matter to them over time, pulling it away from the underdense locations. The former eventually grew into clusters, and the latter became voids.

Because voids have little matter, they act like hills on anything passing through them [*see box on page 33*]. As a particle moves into the void, away from the stronger gravitational pull of surrounding higher-density areas, it slows down like a ball rolling up a hill; once it starts to move out of the void toward the dense areas, it accelerates as if rolling down the hill. CMB photons behave similarly, although they do not change speed (the speed of light is always constant). Instead they change in energy, which is directly proportional to their temperature. As a photon enters a void, it climbs the hill and loses energy—that is, it cools down. Rolling down the hill on the other side, the photon regains its energy. Hence, it would arrive on the other side with the same temperature it started out with—if the universe were not expanding at an accelerating rate.

In the past two decades, though, scientists have discovered that the cosmos is not only expanding but that this expansion seems to be speeding up. Most cosmologists attribute the acceleration to dark energy, a putative kind of negative pressure throughout space that seems to be counteracting the inward pull of gravity. The acceleration of the universe adds a wrinkle to the hill scenario—from the perspective of our CMB photon, it means that while it crossed the void, the plain surrounding the hill effectively rose, so that the flat ground on the far side became higher than it was on the near side. As a result, the photon cannot regain all the energy it lost when it climbed the hill. The net effect is that CMB photons would lose energy when crossing a void. Consequently, we should see temperature dips on the microwave background near low-density regions. This phenomenon is called the integrated Sachs-Wolfe (ISW) effect. The effect also applies to superclusters, but in that case, photons would gain net energy when crossing vast areas with extra mass.

The ISW effect is expected to be tiny. Even for large voids, it would typically create temperature variations smaller than the average fluctuations in the CMB, which can vary by roughly one part in 10,000 because of slight differences in the density of the nascent universe when the light was released. But in the case of a truly huge void—a supervoid—the difference, we realized, might be enough to generate the cold spot. And if we could demonstrate that the supervoid existed and was the driving force behind the anomaly, we would do more than explain

COURTESY OF ROB RATKOWSKI AND PS1 OBSERVATORY

the cold spot. We would also offer a smoking gun for dark energy because the ISW effect can occur only if dark energy is operating on the universe, accelerating its expansion.

THE HUNT FOR A SUPERVOID

ASTRONOMERS FIRST BEGAN looking for a supervoid that overlapped with the cold spot in 2007. Detecting such a large structure is harder than it sounds. Most astronomical surveys produce 2-D pictures of the sky without telling us how far away the objects in the pictures lie. The galaxies we see could all be clumped together, or they could be widely spaced out along our line of sight. Astronomers must gather further information about each galaxy individually to try to estimate its distance—a laborious and often prohibitively expensive task.

In 2007 Lawrence Rudnick of the University of Minnesota and his collaborators were looking at the NRAO VLA Sky Survey (NVSS) catalog of galaxies in radio waves and found that a region of space approximately aligned with the cold spot has fewer galaxies than average. Although the NVSS did not contain any data on the specific distances to the galaxies in the survey, the astronomers knew that most NVSS galaxies are very far from us. Based on the data, they hypothesized that an extremely vast supervoid that could produce the cold spot through the ISW effect might be present roughly 11 billion light-years away. One difficulty with this idea was that light reaching us now would have crossed through such a distant supervoid a long time ago—roughly eight billion years in the past. (It would not have been a full 11 billion years ago, because the universe has expanded to twice to its size since the light was emitted.) At such an early cosmic epoch, dark energy would not have been as strong a force as it is today, and so the ISW effect might have been too slight to yield the cold spot.

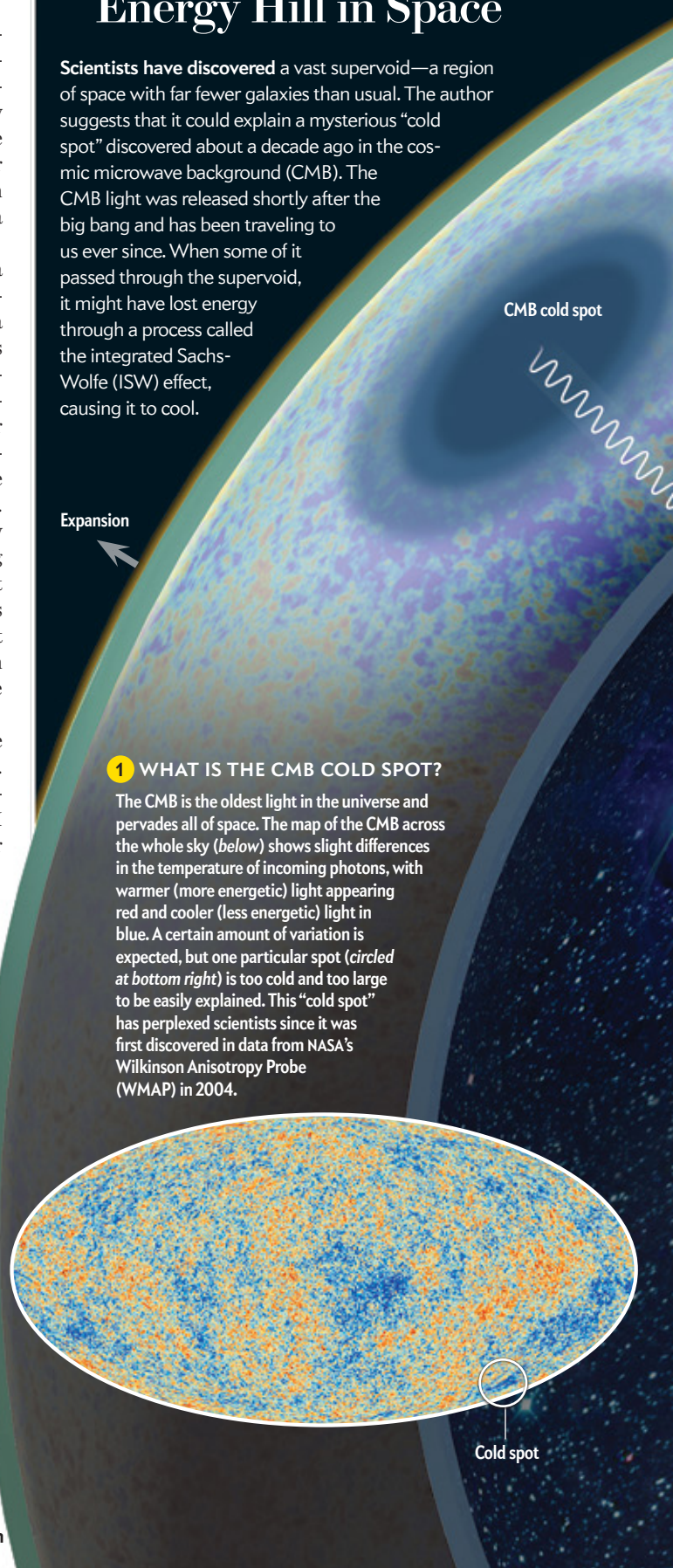
Rudnick's work, although it failed to turn up definitive evidence for a supervoid, nonetheless caught my attention. Along with Ben Granett and Mark Neyrinck, then a Ph.D. student and a postdoc, respectively, at the University of Hawaii, I conducted a statistical analysis to determine how often smaller features in the CMB—relatively warm or cool areas that were less extreme than the cold spot—appeared to overlap with smaller known clusters and voids in the universe, and we found that such overlaps were common. Even though none of these known structures could account for the cold spot, the results convinced us that the search for a supervoid that overlapped with the cold spot was not foolhardy and was worth continuing.

We then designed observations with the Canada-France-Hawaii telescope (CFHT) that targeted several small fields in the cold spot area and counted the number of galaxies in them. To our disappointment, when we made the observations in early 2010 we found no sign of a supervoid at the distance that Rudnick predicted. In fact, we could rule out the presence of a supervoid beyond distances of about three billion light-years. A similar search conducted by Malcolm Bremer of the University of Bristol in England and his collaborators yielded no results either.

At the same time, the statistical significance of the original paper by Rudnick was reevaluated by peers and turned out to be lower than thought. Thus, for a while it

A Cold, Lonely Energy Hill in Space

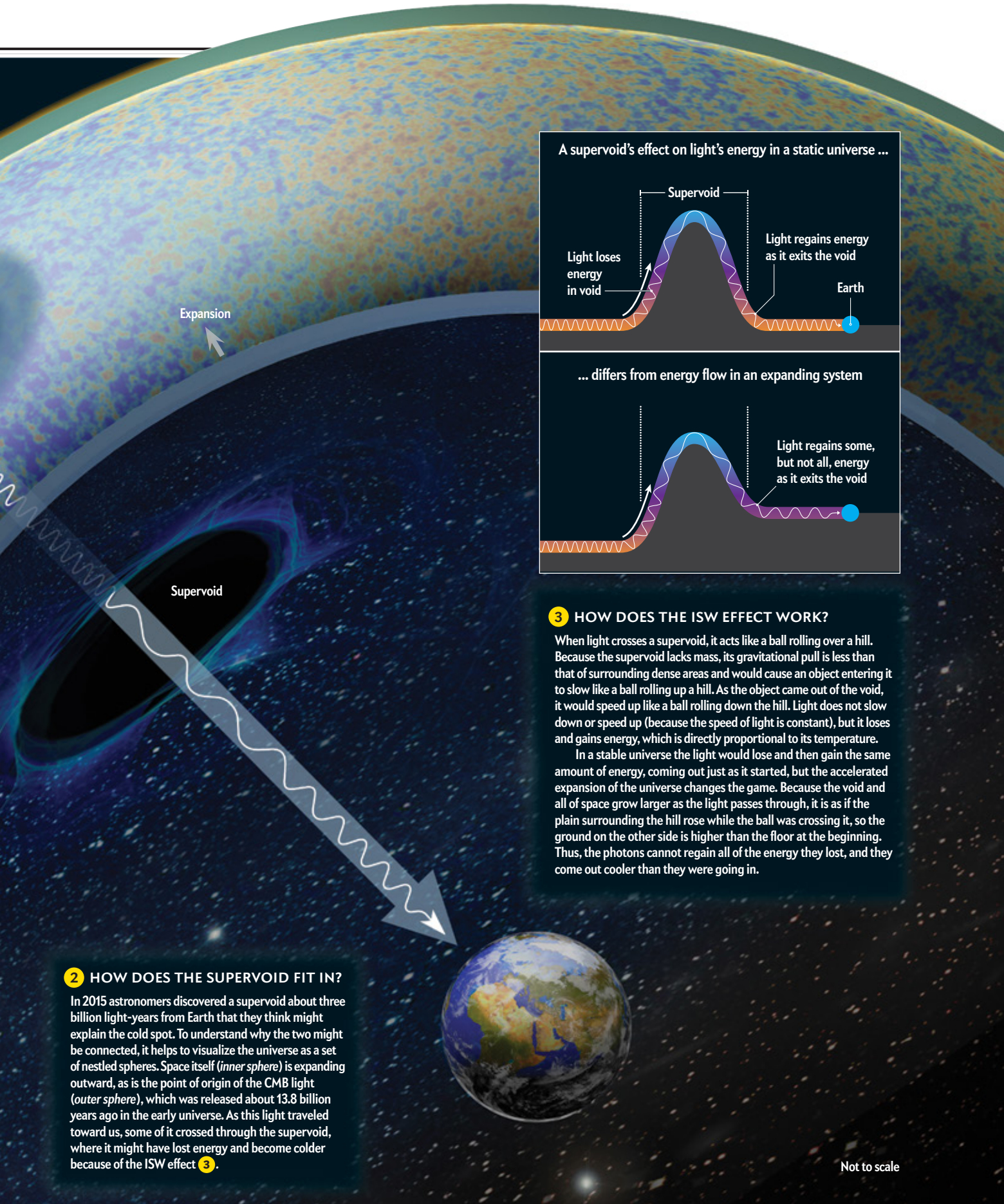
Scientists have discovered a vast supervoid—a region of space with far fewer galaxies than usual. The author suggests that it could explain a mysterious "cold spot" discovered about a decade ago in the cosmic microwave background (CMB). The CMB light was released shortly after the big bang and has been traveling to us ever since. When some of it passed through the supervoid, it might have lost energy through a process called the integrated Sachs-Wolfe (ISW) effect, causing it to cool.



1 WHAT IS THE CMB COLD SPOT?

The CMB is the oldest light in the universe and pervades all of space. The map of the CMB across the whole sky (*below*) shows slight differences in the temperature of incoming photons, with warmer (more energetic) light appearing red and cooler (less energetic) light in blue. A certain amount of variation is expected, but one particular spot (*circled at bottom right*) is too cold and too large to be easily explained. This "cold spot" has perplexed scientists since it was first discovered in data from NASA's Wilkinson Anisotropy Probe (WMAP) in 2004.

COURTESY OF ESA AND PLANCK COLLABORATION (*CMB*)



2 HOW DOES THE SUPERVOID FIT IN?

In 2015 astronomers discovered a supervoid about three billion light-years from Earth that they think might explain the cold spot. To understand why the two might be connected, it helps to visualize the universe as a set of nestled spheres. Space itself (*inner sphere*) is expanding outward, as is the point of origin of the CMB light (*outer sphere*), which was released about 13.8 billion years ago in the early universe. As this light traveled toward us, some of it crossed through the supervoid, where it might have lost energy and become colder because of the ISW effect 3.

3 HOW DOES THE ISW EFFECT WORK?

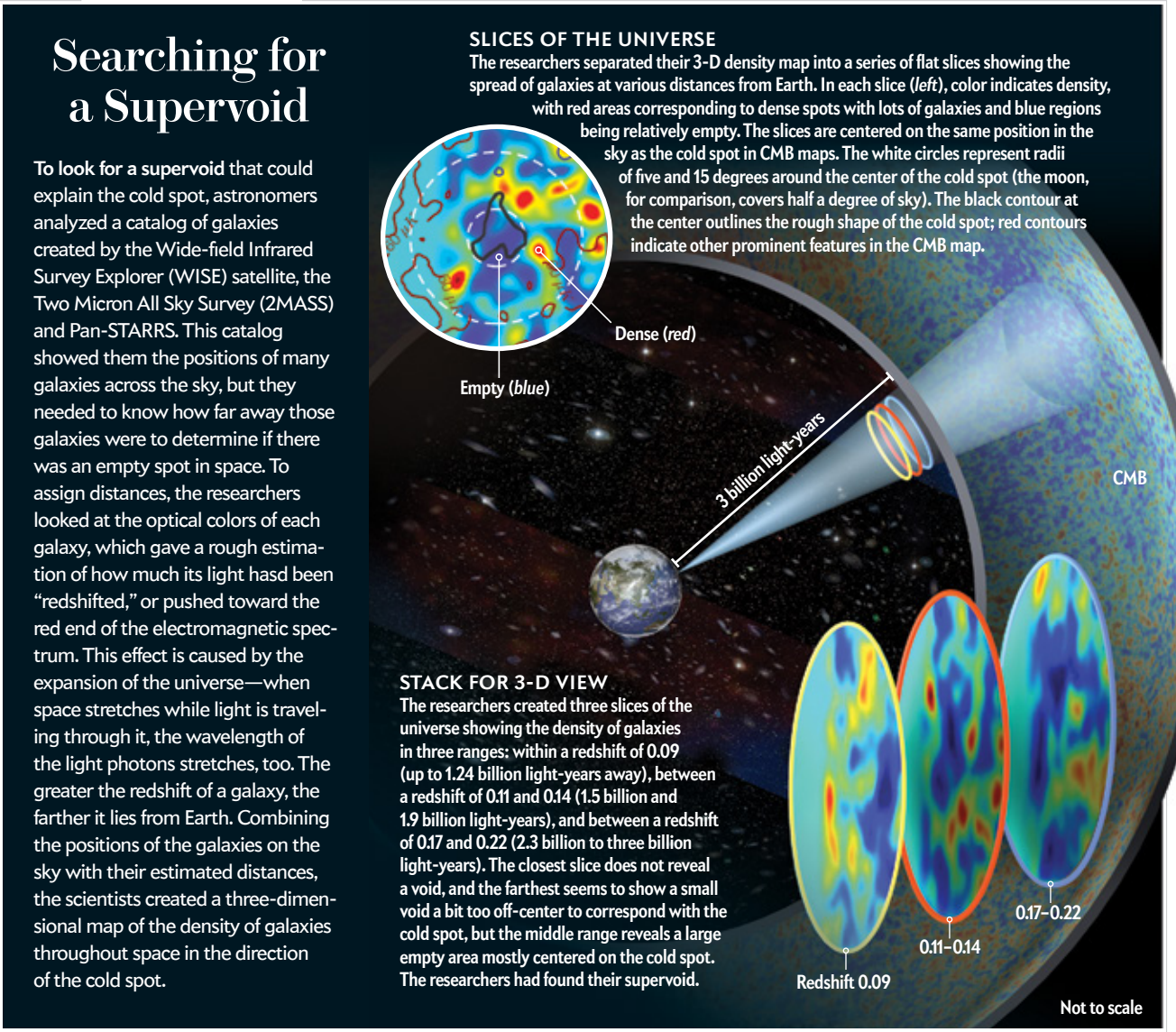
When light crosses a supervoid, it acts like a ball rolling over a hill. Because the supervoid lacks mass, its gravitational pull is less than that of surrounding dense areas and would cause an object entering it to slow like a ball rolling up a hill. As the object came out of the void, it would speed up like a ball rolling down the hill. Light does not slow down or speed up (because the speed of light is constant), but it loses and gains energy, which is directly proportional to its temperature.

In a stable universe the light would lose and then gain the same amount of energy, coming out just as it started, but the accelerated expansion of the universe changes the game. Because the void and all of space grow larger as the light passes through, it is as if the plain surrounding the hill rose while the ball was crossing it, so the ground on the other side is higher than the floor at the beginning. Thus, the photons cannot regain all of the energy they lost, and they come out cooler than they were going in.

Illustration by Moonrunner Design

Searching for a Supervoid

To look for a supervoid that could explain the cold spot, astronomers analyzed a catalog of galaxies created by the Wide-field Infrared Survey Explorer (WISE) satellite, the Two Micron All Sky Survey (2MASS) and Pan-STARRS. This catalog showed them the positions of many galaxies across the sky, but they needed to know how far away those galaxies were to determine if there was an empty spot in space. To assign distances, the researchers looked at the optical colors of each galaxy, which gave a rough estimation of how much its light hasd been "redshifted," or pushed toward the red end of the electromagnetic spectrum. This effect is caused by the expansion of the universe—when space stretches while light is traveling through it, the wavelength of the light photons stretches, too. The greater the redshift of a galaxy, the farther it lies from Earth. Combining the positions of the galaxies on the sky with their estimated distances, the scientists created a three-dimensional map of the density of galaxies throughout space in the direction of the cold spot.



looked like we needed to give up on the ISW explanation for the cold spot.

There was a silver lining, however. We found a hint in our data that a supervoid might be lurking close to us. Paradoxically, finding one nearby is harder using the type of data we obtained with the CFHT: in the fields we observed, the larger the distance from us, the larger the physical area that was covered, and thus the more accurate the galaxy counts could be. Close to us, where the volume in our field was small, we had low statistical significance. Consequently, we had only about a 75 percent chance that the hint in the low galaxy count we saw close up indicated a supervoid—at scientific standards, this amounts to a mere glimmer of hope. To decide the matter, we needed to image a much larger area, essentially covering the full cold spot region. At the time, we could not obtain enough coverage with the telescopes available to us; Granett graduated with his Ph.D. and is now at the Astronomical Observatory of Brera in Italy, and Neyrinck went on to Johns Hopkins University.

A LUCKY BREAK

FORTUNATELY FOR ME, within a few years I would be able to obtain new data. About the time I was saying good-bye to Granett and Neyrinck, the Institute for Astronomy at the University of Hawaii, my home base, finished constructing a new telescope: PS1, the initial observatory for the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). It was exactly what I needed. Equipped with the world's largest camera, with 1.4 gigapixels, the telescope is located at 10,000 feet above sea level on the volcano Haleakala on Maui.

In May 2010, in a consortium with several other universities, my colleagues and I started to map three quarters of the sky with PS1. I remember trying to convince Nick Kaiser, then the principal investigator of Pan-STARRS, that we should map the cold spot area before anything else once the instrument was turned on. Although that did not happen, the region was within the area that was to be surveyed in the telescope's first few years, and the measurements I needed would come in little by little.

SOURCE: "DETECTION OF A SUPERVOID ALIGNED WITH THE COLD SPOT OF THE COSMIC MICROWAVE BACKGROUND," BY ISTVÁN SZAPUDI ET AL., IN *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY*; VOL. 450, NO. 1; JUNE 11, 2015 (*inset*)

SCIENTIFIC AMERICAN ONLINE Watch a video about the accidental discovery of the CMB at ScientificAmerican.com/aug2016/cold-spot

Illustration by Moonrunner Design

While we were eagerly awaiting these new data, I started working with then graduate student András Kovács to use the publicly available CMB observations from the Planck and WMAP satellites, along with a newly released galaxy data set based on observations in infrared light by NASA's Wide-field Infrared Survey Explorer (WISE) satellite to study the ISW effect and, if possible, to search for a supervoid.

Kovács visited me in Hawaii several times for a few months at a time, and during the summers I visited Budapest, where he was studying at Eötvös Loránd University. Otherwise, we had weekly teleconferences, and because of the 12-hour time delay between Honolulu and Budapest, we often had conversations that ran deep into the night in European time. During one of these early sessions, I asked him to find the largest low-density regions, or voids, in the WISE catalog of galaxies. A few days later he sent me an e-mail with images and coordinates of the biggest voids in the catalog. Reading his message, I immediately realized that one of the voids he found coincided with the same region of the sky where the cold spot is. I had not yet told Kovács of my interest in a link between a supervoid and the cold spot, and so the finding was doubly exciting to me: with Kovács not knowing to look for the cold spot connection, the finding could not have been biased by hope for evidence of a relation. Because WISE finds galaxies that are closer than those in the NVSS data set, this was the second clue that perhaps we should look for the supervoid nearby.

From this point, we worked for years to turn our initial clues into a discovery. We used a combined data set of galaxies from WISE, Pan-STARRS and the Two Micron All Sky Survey (2MASS), but we needed to assign distances to these galaxies. One way of measuring distance is to observe an object's "redshift"—the amount that its light has been shifted toward the red side of the electromagnetic spectrum. The farther away a galaxy is, the faster it recedes from us, and the greater its redshift is. Although we did not have access to precise redshift measurements for our galaxies, we could estimate their approximate redshifts by analyzing their colors, comparing our guesses of a galaxy's un-redshifted brightness in various color bands with what we observed.

Finally, we could assign a distance to each galaxy in the direction of the cold spot, and we created a series of tomographic slices—flat pictures of the universe corresponding to different distances from Earth. The first set of images looked like vertical slices of an apple, revealing a supervoid that is approximately spherical and growing toward its center. It turns out this giant void has been hiding very near us, about three billion light-years away, which is why it was so hard to discover.

In the next few months we looked over the statistics of our data and found that the evidence for the supervoid is overwhelmingly significant—in other words, we are extremely assured of the existence of a low-density region aligned with the cold spot. And this supervoid, in fact, is huge: 1.8 billion light-years across, making it possibly the largest structure ever identified by humanity. It is probably a very rare object—cosmological theories suggest there should be only a few more of these within our observable universe.

UNDERSTANDING THE COLD SPOT

WE HAD FINALLY FOUND our supervoid. We knew from our earlier study that voids and clusters have a measurable effect on the CMB, producing small cold and hot spots. And the supervoid we found was indeed aligned with the most significant of anomalies in the CMB. Puzzle solved, right?

Not quite. The mere presence of the supervoid and even its alignment with the region of the cold spot are not enough to definitively conclude that one causes the other. They could be lined up by chance. Our analysis, though, conservatively estimates that the possibility that the supervoid created the cold spot is 20,000 times more likely than the chance that it was just a coincidence.

We have a bigger problem, however. Although the supervoid is in the right place to explain the cold spot, it is not quite the right size. To explain why the cold spot is so much cooler than the average CMB temperature, the supervoid would need to be even larger than it seems to be, perhaps by a factor of two to four. This discrepancy is so hard to stomach that some scientists think the fact that the supervoid overlaps with the area of the cold spot is merely a fluke. They suggest we look for other explanations, such as the possibility that galaxies are releasing less radiation into space than we expect—a phenomenon that could mimic the ISW effect to some extent. Also, although our observations clearly prove the existence of the supervoid, we cannot be sure enough of its size, shape and position to make precise calculations about the effect it should have. In particular, if the shape of the supervoid is elongated toward us, or if several spherical voids are stacked next to one another in the direction of the cold spot (like a snowman), then the void could more easily explain its presence. Thus, we do not yet know how much of a difficulty the size of the supervoid poses for our theory.

We need more data. Already we are planning to repeat our study for the full area of the sky that has been mapped with PS1, rather than the initial partial section, using observations that scientists have additionally refined to reduce uncertainties. With this data set we can quantify the divergence between our measurements and theory to determine whether it necessitates modifying our thinking about the ISW effect and voids. It may be that this discrepancy is telling us something interesting. For instance, a class of alternative theories of gravity that diverge from general relativity has a unique signature that would appear only in voids, and if one of these turns out to be correct, the ISW mechanism may operate differently as well. And if our supervoid has offered up a hint of these theories, we may have an exciting opportunity to understand the universe on a deeper level than we currently know.

No matter what, the discovery of the supervoid stands to tell us something significant about physics—perhaps it is proof of the existence of dark energy, or maybe it reveals an even more surprising truth about how gravity operates. In coming years we should know more about the supervoid and thus the nature of the universe we live in. SA

MORE TO EXPLORE

Detection of a Supervoid Aligned with the Cold Spot of the Cosmic Microwave Background. István Szapudi et al. in *Monthly Notices of the Royal Astronomical Society*, Vol. 450, No. 1, pages 288–294; June 11, 2015.

FROM OUR ARCHIVES

Is the Universe Out of Tune? Glenn D. Starkman and Dominik J. Schwarz; August 2005.

scientificamerican.com/magazine/sa

W. Wayt Gibbs is a freelance science writer and editor based in Seattle. He is also executive editor at Intellectual Ventures, an investment company that receives some funding from Bill Gates and the Bill & Melinda Gates Foundation. Gibbs is a contributing editor for *Scientific American*.

EPIDEMIOLOGY

Health Check *for Humanity*

A global effort to develop the most comprehensive picture of the world's health started with the curiosity of a young boy in Niger

By W. Wayt Gibbs

WHEN CHRISTOPHER MURRAY WAS 10 YEARS OLD, HE AND HIS FAMILY PACKED a few suitcases and a portable generator and left their home in Golden Valley, Minn., for a flight to England. From there they traveled by car and ferry to Spain, to Morocco and finally through the Sahara Desert to the village of Diffa in rural Niger. For the next year the family of five, led by a physician father and microbiologist mother, set up and then administered the local hospital. As the young Murray tended the hospital pharmacy and ran errands, he could not help noticing that the citizens of Niger came down with all kinds of odd diseases that nobody had back in Minnesota. He recalls wondering, "Why are people in some places so much sicker than in other places?"

The boy also grew frustrated. He and his family had worked hard helping the inhabitants of Diffa. But at the end of the year "I had a sense that when we left, things weren't that much different," Murray says. "It planted the question: How do you make bigger, longer-lasting changes?"

That question drove Murray, over the next four decades, to push doctors and health ministers to pay more attention to the big picture, the long-term trends that determine why so many individuals die so young from preventable causes. He focused his career on setting up a system that could supply a crucial ingredient

Illustration by Peter and Maria Hoey

that is too often lacking in global health policy: reliable information.

The picture of what ails our species is often blurry, Murray realized, because politicians withhold or fudge embarrassing numbers. And it can be tricky to compare statistics from one country to the next. But there are ways around these problems.

With the help of others, Murray set out to build a new kind of instrument that could bridge the gaps in data and reveal the true state of the world's health, including what needs to be done to reduce the suffering of entire populations for generations to come.

The widespread use of the microscope triggered a revolution in human health in the 19th and 20th centuries by allowing scientists to focus on the smallest actors in human health—the identification of germs, which in turn led to improvements in sanitation, the development of antibiotics and the creation of vaccines. Murray's new instrument would be the opposite of the microscope. It would clarify useful details about illness at its largest scales: in countries, across continents and throughout the human species as a whole. You might call it a macroscope.

A UNIVERSAL LANGUAGE

MURRAY MADE the first stab at developing such an instrument at the World Bank when he and a few others assembled a landmark report in 1993 surveying the burden of human disease worldwide. In 2007 he founded the Institute for Health Metrics and Evaluation (IHME) at the University of Washington in Seattle and started recruiting a global network of collaborators to generate a much more sophisticated and comprehensive macroscope.

Like so many 21st-century innovations, the macroscope is made of software and big data. In one end go gigabytes of health statistics, collected from every corner of the planet and vetted by a multinational team of more than 1,000 scientists. Out the other end come interactive graphics and tables that illuminate with the kind of detail and accuracy never before possible, virtually all the different ways in which people fall ill, get injured or die around the world—from heart attacks to donkey bites. In the middle is supercomputer code that uses clever statistical mathematics to fix biases, identify and throw out unreliable data, and make intelligent estimates for the many parts of the globe where good numbers simply do not exist.

After 10 years and tens of millions of dollars in development, the system is now producing snapshots of the health of *Homo sapiens* with nearly the regularity of an annual physical. The IHME released its first expanded set of statistics in 2012 and another in 2014. An update, reflecting data collected in 2015, is due to appear in September, with annual checkups to follow. With each successive release, the snapshots—not only of the present but also those of the past—get more accurate, detailed and complete.

The reports, collectively known as the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD, for short), have spotlighted surprising trends in ailments as diverse as air pollution, kidney disease and breast cancer—and in countries both poor and rich. Some of the findings have also ignited controversy because they contradict those published by the World Health Organization (WHO) and other branches of the United Nations.

Like many others in the developing world, however, Agnes Binagwaho, health minister of Rwanda, is among the macroscope's fans. "It's not a simple new tool—it's a revolution," she said at its official unveiling in 2013. "We are going to have a universal language for scientists, a universal language for [health] policy…, and our people are going to have better lives."

BEGINNING IN A BARN

THE IMPETUS FOR the macroscope arguably originated in the early 1990s with Dean Jamison, an economist then at the World Bank who was assembling an in-depth report about the interplay of health and economics around the globe. Jamison commissioned Murray to survey the economic toll exacted by disease and injury in 1990. Murray was later joined in the effort by Alan Lopez, an epidemiologist then at the WHO.

"Most of our work was done in Chris's barn in Maine," says Lopez, who now works on the GBD at the University of Melbourne in Australia. "We hunted mercilessly for all available data on about 120 diseases and 10 risk factors. We were working 20 hours a day, totally obsessed."

Compared with the latest GBD, which will cover 317 causes of death and disability in every country with a population greater than 50,000 people, the World Bank report, which came out in 1993, was rudimentary. It turned out to be enormously influential nonetheless. Microsoft co-founder Bill Gates cites it as one reason that he and his wife, Melinda Gates, decided to deploy most of their philanthropy—more than $37 billion so far—into efforts to curtail infectious disease [*see box on page 40*]. And in 1998 Gro Harlem Brundtland, who was then director general of the WHO, hired Murray to build a similar system for her agency.

Murray and his colleagues brazenly ranked the comparative performance of the health care systems in various nations. The rankings provoked a firestorm of criticism, both from academic epidemiologists and from government officials unhappy with the rank assigned to their nations (the U.S. was 37th; Russia was 130th). The WHO, which answers to its member nations, has never published such rankings since. "It became this extraordinary political battle," Murray says. The fight was so distracting that his project to measure the global burden of disease foundered, and he left the WHO to go to Harvard University in 2003. The hard lesson, Murray says, was that "it is crucial that we firewall this work against government influence."

He started looking for private money to launch an academic institute that would be free from political meddling.

IN BRIEF

Christopher Murray, a physician and economist, has devoted decades to a quest to assemble good measurements of disease and disability worldwide as a way to make enduring progress in human health.

Numbers for many health problems, however, are lacking, misleading or hard to compare across national borders.

Murray leads a team of hundreds of experts that has been gathering better data from around the world to feed a sophisticated supercomputer model to produce more helpful and trustworthy figures.

Results so far have highlighted, among other things, unexpected progress in providing safe water as well as a lack of good information about typhoid, measles and hepatitis.

On a trip to Seattle, Murray met with Bill Gates, who says he agreed to the proposal almost immediately. In 2007 the Bill & Melinda Gates Foundation donated $105 million to launch the IHME. Work on a macroscope was soon under way.

MODELING MISERY

IT IS INDEED A MESSY BUSINESS, accounting for human suffering across a disorganized world. But Murray found other researchers who shared his and Gates's confidence that the flaws in statistics available from governments, advocacy groups, the WHO and other U.N. agencies could be fixed—and that better numbers would save lives in the long term. Mismeasurement, bias and missing data: these were the demons they needed to battle.

Much of the raw data fed into the system comes from health ministries, aid organizations or the scientific literature, but it first goes through rigorous quality control. "Whenever we get a new data set, our first question is, 'What's wrong with it?'" Lopez says. "We scrub it for garbage coding—deaths from 'an act of God,' for example—and use scientific methods to reallocate those to a well-defined list of causes." This process helps to control for certain outliers, such as France's seemingly low death rate from heart disease despite a high prevalence of risk factors. It turns out that French physicians tend to mark down some other coexisting cause when people die of heart attacks. "That cultural practice accounts for about half of the so-called French paradox," says Theo Vos, one of the lead scientists at the IHME.

Hundreds of scientists from across the globe who have expertise in each disease and region also adjust data sets to account for variations in how diseases are defined. By putting all the results on the same footing, Lopez says, "we can compare cancer in Hungary with cancer in El Salvador or South Africa or anywhere else."

Then there is political influence. "It's increasingly hard for governments to dictate numbers to the WHO and the U.N.," Murray says, "but there are subtle effects. UNAIDS puts out estimates of HIV/AIDS prevalence each year, for example, but China and some other countries do not like them. So they do not publish these numbers for those countries"—83, as of 2015.

The problem of missing data is the thorniest. In many of the sickest parts of the world, comprehensive health statis-

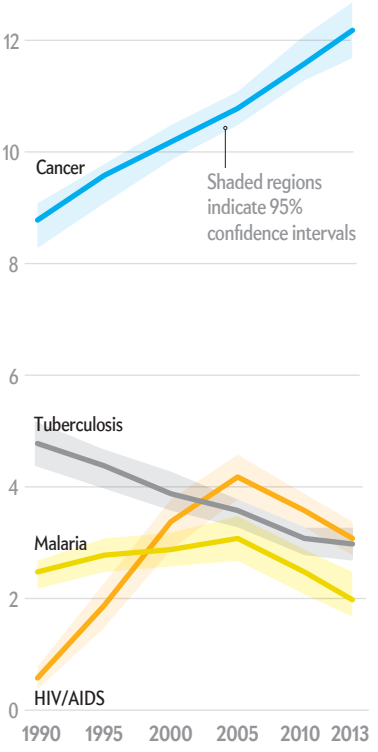
FINDINGS

Cancer—Curse of the Developing World as Well

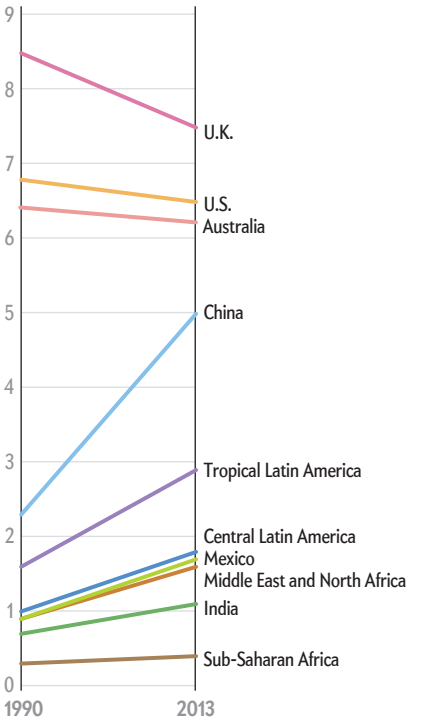
Cancer is thought of as a rich-country problem, but the views produced by the macroscope show that to be a misconception. As standards of living have increased in Central America, women are living longer, and breast cancer is taking a much greater toll on their health. Among women in Mexico, for example, death rates have soared by 75 percent since 1990—or 17 percent after adjusting for the effects of an aging population. Neighboring countries have seen similar increases.

More broadly, cancers of all kinds now claim about 50 percent more lives in low- and middle-income parts of the world than do HIV/AIDS, tuberculosis and malaria combined (A). Yet the international community spends relatively little on preventive methods—such as vaccines for the cancer-related human papillomavirus or education about the risks of smoking, bad diet and inactivity—that have worked well to reduce cancer incidence in some richer countries (B).

A Deaths in the Developing World (percent of total)



B Years of Healthy Life Lost to Breast, Lung and Colorectal Cancers (percent of DALYs)



WHAT IS A DALY?

"There is a lot more to good health than just avoiding death," Christopher Murray says. To quantify the concept of ill health more usefully, he and Alan Lopez have long used a unit called a DALY, or disability-adjusted life year.

In principle, one DALY equals the loss of one year of healthy life. To calculate it, you have to assume that everyone, rich or poor, young or old, is entitled to attain maximum life expectancy—age 86, in the most recent study—free of suffering. A five-year-old who dies suddenly of malaria thus represents 81 DALYs; an 85-year-old who has lived a life of perfect health but is killed crossing the street accounts for just one DALY. Disabilities that worsen life but do not necessarily shorten it accumulate DALYs, too, via a weighting scheme derived from public surveys of physicians and, more recently, people from all walks of life. These panels rank, for example, the debility imposed by blindness versus suffering caused by prostate cancer.

SOURCE: INSTITUTE FOR HEALTH METRICS AND EVALUATION, GLOBAL HEALTH DATA EXCHANGE (GHDX) www.healthdata.org

Graphic by Nigel Hawtin

tics simply do not exist. The GBD team fills the gaps in two ways. First, the investigators hoover up surveys performed by a small army of workers moving village to village—in some places, house to house—to gather information from handwritten records and, where necessary, interviews with people about sickness and death in their families. The Million Death Study, under way in India, is conducting such work on a grand scale; its preliminary results in 2010 suggested that malaria takes at least 10 times more lives in India than had been reported by the WHO, which relied mainly on hospital records and thus missed many of the deaths that occurred at home.

The second way to fill in missing data is to extrapolate it from various common patterns that researchers have observed for specific diseases, injuries and risk factors. Malaria is typically worse during or just after the wet season, for example; cancer rates are higher among the elderly; and HIV is more prevalent in countries that border on nations where many people are HIV-positive. Such correlations allow one to use statistical indicators that are well measured in one part of the world to make reasonable estimates about what the health numbers should be in another part where data are incomplete.

"We have a database of 200 of these [well-measured variables], ranging from latitude, population density and rainfall to how many cigarettes people smoke and how many pigs are consumed," Vos says. The system generates myriad combinations of these variables, plugs them into a large number of mathematical models of differing form, and then tests to see which combination produces the most consistently accurate predictions for each disease.

This approach, known as ensemble modeling, has been widely used in weather forecasting, finance and insurance, among other areas. But it falls "outside the comfort zone" of many epidemiologists, Vos says, in part because it requires enormous computational horsepower.

The GBD now tracks more than 1,000 health indicators for 188 countries covering 25 years, which are in turn double-checked against 20 to 40 statistical models. The team also runs each model 1,000 times to wiggle all the data points within their range of plausible values, a technique that allows the researchers to bracket their estimates with error bars indicating the degree of uncertainty. The computations are run on the IHME's supercomputer, where 12,000 high-performance processing cores churn away at the math for four days to complete a single snapshot for the planet—a kind of report card on the health of the human species.

"Just the fact that somebody is trying to publish these numbers and put error bars on them focuses the discussion," Gates says. "Now that the IHME has created a central repository, you no longer have to read hundreds of articles and try to assemble the big picture yourself. Peo-

Q&A

Bill Gates on Global Health

Bill and Melinda Gates have been among the principal funders of many global health initiatives, including efforts to reduce the burden of HIV and tuberculosis and to eradicate polio and malaria. The Bill & Melinda Gates Foundation also paid to create the Institute for Health Metrics and Evaluation (IHME) and has bankrolled its ongoing work to measure the occurrence of various maladies and their causes around the world, a project known as the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD, for short). In an interview with *Scientific American*'s contributing editor W. Wayt Gibbs, Bill Gates reflected on the origins of these efforts and the progress that has been made to date. An edited excerpt follows.

Scientific American: You were an early backer of Christopher Murray and his push to create an independent organization, the IHME, to pull together rigorous statistics on human health worldwide largely independently of the World Health Organization [WHO]. How did you two meet and decide on this course?

Bill Gates: I met Chris in 2001 when he was working for the WHO and was doing the first-ever ranking of national health systems. Some countries were pushing back because they didn't like how he ranked things. This idea that somebody should try to pull together the best understanding of health, particularly for poor countries, was an attractive one. So we gave money to the University of Washington to create IHME.

SA: But the WHO and other U.N. agencies collect and publish lots of health statistics on countries around the world. Why is it necessary to have a whole separate effort to do that?

BG: I love the WHO, and Margaret Chan [the WHO director general] has done a lot of great things. But it is a U.N. agency, and that creates certain complexities. When Chris was doing country rankings inside the WHO, he found out that both funding and their inability to take controversial positions were limiting. Ranking their customers ended up being tough for them to do.

SA: What's your high-level impression of the collective health of our species? Are we healthier than we were 20 years ago?

BG: We are so much healthier now than in the past. It's one of those mind-blowing good news stories. Because it is good news, and there is no villain, it doesn't get the attention it deserves. But if you look at countries like Vietnam, Cambodia, Sri Lanka, Rwanda, Ghana—basically all communicable diseases are going down. The only infectious disease we work on that is now going up is dengue.

Yes, the burden of noncommunicable diseases is increasing in developing countries. We do have a diabetes epidemic. We do have an explosion in medical costs. On a global basis, though, what's happened in the past 20 years is incredibly dramatic.

SCIENTIFIC AMERICAN ONLINE Read more of the interview with Bill Gates at ScientificAmerican.com/aug2016/bill-gates-interview

ple can argue over specific numbers, but if the right process is in place, the error bars will either get bigger or some study will be done, and the state of knowledge will get better."

SURPRISING RESULTS

THE INITIAL RELEASE of GBD numbers in 2012 sent ripples even through countries that pride themselves on their health information systems. Officials in the U.K. were alarmed, for example, to see that the health of Britons has been lagging behind that of their European neighbors. "The risk-factor analyses led them to change their priorities and put more emphasis on diet," Murray says. At least 33 countries, including China, Brazil, Germany and Russia, are now undertaking similar studies of their own populations to improve the quality and detail of their health statistics—data that will flow into the global macroscope.

Some of the new pictures of human health produced by the GBD system have stirred up debate because they contradict numbers long accepted as authoritative. A GBD analysis of HIV prevalence published in 2014, for example, suggested that the UNAIDS estimates for 2005 to 2012 were too high by 17 to 19 percent, a difference of about 6.6 million infections and 635,000 deaths. If correct, the low numbers would raise the question of whether certain prevention and treatment strategies are working better than expected and, if so, whether they might be used more widely.

In another controversial finding, the IHME estimated that in 2013 about a third of those killed by malaria were adults. It has long been thought that whereas the mosquito-borne illness sickens many older people, malaria fatalities are largely limited to children. "Ninety percent of the field thinks [Murray is] wrong," Gates says. But within the next few years better data gathering should settle the dispute.

The GBD results also contain heartening revelations. They report, for instance, that the burden of death and disability from diarrheal diseases—which are caused primarily by unsanitary water—dropped by 70 percent from 1990 to 2013. Indeed, dirty water has dwindled to become so much less of a threat than other risks that Murray and his colleagues suggest that it may be wise to redirect aid in some regions from water projects to, say, preventing road injuries. Traffic accidents are on the rise in part because children who used to die from waterborne illnesses now survive to become pedestrians, bicyclists and teen drivers.

By the same token, the system also highlights blind spots in the global surveillance system. "It drives us crazy that we don't really know where typhoid and cholera are," says Gates, who now takes GBD charts with him to meetings with officials and aid workers. Because recording of these diseases is so spotty, the IHME reckons that typhoid may account for as few as six million years of healthy life lost worldwide—or as many as 18.3 million years. Giant uncertainties similarly surround the impacts of whooping cough, measles, and hepatitis A and C.

Murray remains confident that the view through the macroscope will sharpen with time. Leaders could then shift their focus from the numbers of people sick and dying from each disease to the trend from year to year. That is what happened in macroeconomics, he notes. Individuals no longer pay much attention to median income, total number of jobs or the dollar value of the GDP; it is the rate of change that matters more. We stop asking, "Can we do better?" Murray says. The question becomes, "How can we improve faster?" SA

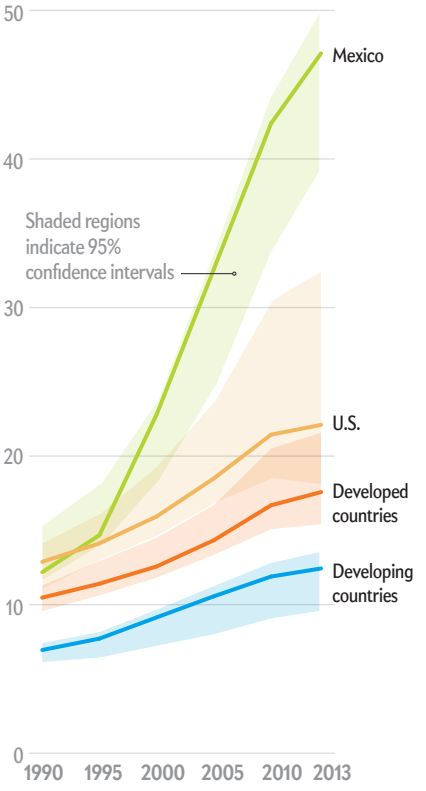
RISING TREND

The Mystery of Kidney Disease

Chronic kidney disease is soaring. The IHME estimates that in the U.S., the mortality rate from persistent kidney problems has jumped about 72 percent since 1990; by 2013 three Americans were dying of kidney disease every year for every two felled by breast cancer. The situation is even worse elsewhere. In Mexico, chronic kidney problems were responsible for just one in 40 deaths in 1990; by 2013 they were to blame for nearly one in 11.

The GBD study suggests that increasing prevalence of obesity and diabetes may explain about a quarter of the rise, with high blood pressure accounting for another quarter. "But it seems like it is on the rise for other reasons as well," the IHME's Murray says. "There is quite a controversy as to why that is."

Deaths Attributed to Chronic Kidney Disease
(rate per 100,000 people)



SOURCE: INSTITUTE FOR HEALTH METRICS AND EVALUATION, GLOBAL HEALTH DATA EXCHANGE (GHDX) www.healthdata.org

MORE TO EXPLORE

Epic Measures: One Doctor, Seven Billion Patients. Jeremy N. Smith. Harper Wave, 2015.

Global, Regional, and National Disability-Adjusted Life Years (DALYs) for 306 Diseases and Injuries and Healthy Life Expectancy (HALE) for 188 countries, 1990–2013: Quantifying the Epidemiological Transition. Christopher J. L. Murray et al. in *Lancet*, Vol. 386, pages 2145–2191; November 28, 2015.

Interactive visualizations of the Global Burden of Disease results: www.healthdata.org/results/data-visualizations

FROM OUR ARCHIVES

Six Billion in Africa. Robert Engelman; February 2016.

scientificamerican.com/magazine/sa

Graphic by Nigel Hawtin

{ SPECIAL REPORT ON EDUCATION }

<2016>

THE CODING REVOLUTION

From the White House to Silicon Valley, the call for all students to learn computer programming is growing louder. Yet some critics of this vision point to logistical hurdles, and others worry about industry dictating the curriculum. Is coding for all a realistic goal—and is it one that American schools should be pursuing?

By Annie Murphy Paul

Illustration by Patric Sandri

"*Yes!* We got here first!"

Annie Murphy Paul is a frequent contributor to the *New York Times*, *Time* magazine and Slate. Paul is author of *The Cult of Personality Testing* and *Origins*, which was included in the *New York Times'* list of 100 Notable Books of 2010. Her next book, forthcoming from Crown, is entitled *Brilliant: The Science of How We Get Smarter.*

Allie and Lauren, two sixth graders at Loyola Elementary School in Los Altos, Calif., bound into Sheena Vaidyanathan's classroom a few minutes before the start of fifth period. The girls have a long-running competition with a couple of their classmates, William and Blake, over who can arrive the earliest at their computer programming class.

COMPUTER SCIENCE CLASSES: Nancy Se teaches at Augustus F. Hawkins High School in South Los Angeles, where 99 percent of the student body is African-American or Latino and 75 percent is economically disadvantaged.

The two girls take their seats at the row of new Apple desktop computers and immediately start on the assignment Vaidyanathan has provided: finding and fixing errors in a computer program. It is the kind of activity, exacting but important, that occupies much of the time of professional programmers.

A bell sounds, and more students traipse in. Vaidyanathan, a petite woman with a warm and friendly manner, welcomes them with a smile.

"What are we doing today, Mrs. V?" asks one boy as he enters.

"Debugging a program," she responds.

"Sweet!" he exclaims and darts over to a computer.

Proponents of universal coding instruction would like to see such scenes repeated all over the country. These champions include business leaders eager to employ the next generation of engineers and programmers, as well as government officials looking to ensure the U.S.'s competitiveness in the global economy. "Every student deserves a chance to learn this essential 21st century skill," tweeted Microsoft co-founder Bill Gates earlier this year. Gates and others maintain that coding is a new literacy, as important as knowing how to read or to do math. In a 2008 essay, Marc Prensky, an author and speaker who coined the term "digital native," wrote, "I believe the single skill that will, above all others, distinguish a literate person is programming literacy."

These advocates have pointed to the high demand for computer programmers and the opportunities for advancement in the field—opportunities that, they say, will continue to expand in coming years.

Obama administration officials sketch an ambitious vision for computer science education in the U.S. in which our students keep pace with those in other nations—the U.K., they note, began requiring every student to learn to program in 2014—and persistent achievement gaps in our own country between white and affluent students on the one hand and minority and disadvantaged students on the other are closed with the help of coding for all.

Achieving this vision will not be easy, however. The extension of coding instruction to all U.S. students faces steep logistical chal-

IN BRIEF

Champions of universal coding believe computer science instruction in public schools can close achievement gaps among socioeconomic groups and help U.S. students keep pace with those in other countries.
But coding for all faces steep logistical challenges, including a shortage of teachers, the absence of an agreed-on curriculum and disparities in students' access to computers.
Some critics argue that coding represents a too narrow technical focus and that it is being pushed on schools by business leaders concerned about their bottom lines.
A potential middle ground involves teaching "computational thinking": habits of mind that include breaking down a problem, designing systems, and running small experiments to see which approaches fail and which succeed. The White House's Computer Science for All Initiative embraces coding as well as computational thinking.

lenges, from a shortage of qualified teachers to a lack of curricular materials. The U.S.'s radically decentralized school system makes it difficult to enact nationwide reform—just ask the architects of the Common Core State Standards—and most schools have yet to update their rules and standards for the information age (computer science courses often do not count toward graduation requirements in math or science, for example). Meanwhile students of different ethnic and socioeconomic backgrounds come to school with enormous disparities in their knowledge of computers; research suggests that schools often perpetuate these gaps by offering deep, substantive teaching to affluent white students and more superficial instruction to minority and low-income pupils.

Moreover, there is a growing recognition that programming skills can form only part of American students' preparation for living and working in the 21st century. Coding is the *practice* of computer science, but students also need the *theory:* an understanding of the underlying principles on which computers operate. Making such "computational thinking" universal will require a massive mobilization both outside school—in the form of extracurricular programs and resources—as well as inside school—by training teachers, revamping courses, integrating computer science into other academic subjects and changing graduation requirements.

TEACHING TO THE CODE

VAIDYANATHAN, who has a master's in computer science and has taught the subject for seven years, was an early proponent of the notion that every student should learn how to code. "And I mean *every* student—girls, boys, special education students, students who don't think they are math or science 'people,'" Vaidyanathan says. But unlike some of her fellow advocates, she tempers her enthusiasm with realism. In an interview between classes, she points out some of the hurdles that stand in the way of achieving this appealing vision. "To begin with, there are not nearly enough computer science teachers to meet what would be an enormous demand," she notes.

According to Advanced Placement (AP) publisher the College Board, only 4,310 U.S. high schools offered an AP exam in computer science in 2015—about 12 percent. Moreover, a 2014 analysis of the organization's data for 2013 found that in three states, there were no female students who took the test; in eight states, zero Hispanic test takers; and in 11 states, not one African-American test taker. (In many of these states, few or even no students took the test at all.) Further, a trained and ready corps of teachers simply is not there—and human teachers, Vaidyanathan insists, are what students need. "If students are learning material that is meaningful and challenging, they are going to get stuck at some point," she says. "They're going to need a teacher who knows them, who can explain the problem in a way they understand, and who can draw on the student-teacher relationship as a source of motivation and support. A Khan Academy video can't do all that."

Not only are there too few computer science teachers, there is also the absence of an agreed-on computer science curriculum. The CSTA has developed a set of standards for kindergarten through grade 12, but these are general in the extreme (stu-

Photographs by Timothy Archibald

dents in grades six through nine should "begin to appreciate the ubiquity of computing and the ways in which computer science facilitates communication and collaboration"), meaning that teachers such as Vaidyanathan are on their own in deciding what and how to teach their students. And in an era of high-stakes math and reading tests, computer science often gets pushed aside altogether. "There is less time in schools' schedules, and less money in schools' budgets, for subjects that are not viewed as essential," Vaidyanathan observes.

Before becoming a computer science teacher and a science, technology, engineering and mathematics (STEM) program specialist in the Los Altos School District, Vaidyanathan worked as a software engineer at information technology giant Unisys and at two Silicon Valley start-ups. Her experience in the tech industry has made her keenly aware of another hitch in the plan to turn every student into a hire-ready programmer: "There's a big difference between learning the basics of coding and knowing it well enough to do it professionally." The wide gap between novice and expert in this field is the reason she pushed her district to begin coding instruction in kindergarten. "Learning coding is like learning a foreign language," Vaidyanathan explains. "We wouldn't expect students to be fluent in French or Spanish because they took a couple of semesters of instruction in high school."

Particularly challenging is the project of extending coding instruction beyond the confines of wealthy, mostly white and Asian communities such as Los Altos. Vaidyanathan's students start out with almost numberless advantages. They enter her classroom equipped with knowledge of computers and how they work; some of them have already begun to learn about coding at home or in extracurricular enrichment programs. The coding class at their public school is supported by a foundation that collects and distributes donations from the families of students enrolled in the district. The district's schools—themselves fully furnished with desktop and tablet computers—are located in the heart of Silicon Valley, and many of their students' mothers and fathers work at the nearby headquarters of Google, Apple or Facebook. These students have been gently but firmly guided down a path by the adults in their lives—a path that leads to abundant opportunity. And yet the presence of such privileged students in computing classes—and later on, in the tech industry and in the field of computer science—is often presented as the product of a "natural" sorting process, based on individuals' innate preferences and abilities.

Jane Margolis is familiar with this presumption and its corollary: that poor students and students of color must not *want* to learn how to code. Margolis, a senior researcher at the University of California, Los Angeles, Graduate School of Education & Information Studies, undertook an intensive study on how computer science is taught in three diverse public high schools in Los Angeles. The result was the 2008 book *Stuck in the Shallow End: Education, Race, and Computing,* a troubling account of what Margolis and her collaborators call "virtual segregation." Students who go to school in affluent communities, they found, are much more likely to have access to a wide range of computer science offerings—courses that are academically challenging, creative and collaborative. Poor students and students of color, in contrast, are often offered only the most basic cut-and-paste computing instruction, often using inadequate equipment.

Even when the schools serving these students possess adequate facilities, they may be "technology rich, but curriculum poor," in the words of Margolis and her colleagues, lacking the elements of a full-fledged education in computer science: "powerful learning experiences in a sequence of classes," along with "years of thoughtful, informed guidance and support." Curricular offerings cannot be one-size-fits-all, she and her co-authors maintain, but rather must take into account racial and ethnic groups' disparate histories of access to technology and training. These "have been so different, the playing fields so uneven, the chasm so deep and wide, that people are living in two different worlds," Margolis and her co-authors observe. The easy familiarity with computers that is taken for granted among affluent stu-

Teach the Prof How to Teach

Few young faculty members arrive on campus ready for the classroom. New programs are changing that

By Jennifer Frederick

As young scientists work their way through graduate school and postdoctoral fellowships, the pressures of writing grant proposals and establishing a research laboratory take priority over teaching. When these students and postdocs eventually get faculty positions, however, few of them have experience in designing and teaching their own courses, and yet they are expected to teach right away. This would not pass muster at a high school. Why should it be acceptable at a university?

Teaching graduate students how to teach offers the chance to instill in future faculty the science of what works—and does not work—in the classroom. For example, many college science professors continue to rely on lectures as the main mode of instruction, even though evidence shows that undergraduates learn best when they actively participate in classroom discussions and activities.

The best teaching strategies also draw on scientific research skills. An instructor hypothesizes that a particular exercise will help students learn a concept and integrates assessment to check the extent to which learning takes place. Just like research, the results of each "experiment" inform the design of subsequent lessons. In contrast, traditional lecture-based courses with only a few high-stakes examinations can leave both instructors and students in the dark about who is excelling or struggling.

Evidence-based engagement strategies are associated with increased student achievement, and active learning can close the achievement gap for students from underrepresented groups as well as first-generation college students. A 2014 analysis by Scott Freeman and his collaborators at the University of Washington looked at hundreds of studies and found that students in active-learning classrooms scored 6 percent higher on exams and were 1.5 times less likely to fail than students in traditional lecture courses. Other studies have found that active learning can shrink achievement gaps by as much as 45 percent. The mechanism explaining why this method of learning works especially well for some students remains elusive. Benefits may result from increased emphasis on

consistently spaced class preparation and frequent feedback that helps students recognize what they know and do not know. These findings show that properly structured college science courses can encourage underrepresented students to pursue science.

Institutions are increasingly recognizing the importance of providing teaching development opportunities for both graduate students and postdocs. Examples of national efforts include the NIH Institutional Research and Academic Career Development Awards fellowships, which are designed to provide postdocs with valuable training as well as teaching experiences in minority-serving institutions. The Center for the Integration of Research, Teaching, and Learning Network targets graduate students and postdocs as future faculty and engages them in campus and virtual-learning communities with opportunities to gain skills for academic careers.

Formal teaching postdoc programs are not common, but the Center for Teaching and Learning at Yale University, which I direct, recently established a teaching program with a unique twist. After a two-year period of training and mentored classroom teaching, the third year is devoted to teaching and related responsibilities at a regional partner institution. Strategic partnerships with a community college and a private institution serving underrepresented and first-generation students ensure that the postdocs gain practical skills by teaching in diverse classroom settings.

The science education literature has yet to report strong connections between professional development programs for faculty and undergraduate student learning outcomes. But a recent study shows that graduate students who engage in more than 55 hours of teaching development feel more confident in the classroom and have greater success securing a faculty position. Follow-up work will demonstrate the impact of teaching development for postdocs and, ultimately, the students in their classrooms.

Postdocs trained in evidence-based teaching are equipped to teach effectively and inclusively. Promoting meaningful engagement in learning benefits everyone, and the particular advantage conferred to underrepresented and first-generation college students is a critical factor for encouraging participation in science.

Jennifer Frederick *is executive director of the Center for Teaching and Learning at Yale University, where she oversees initiatives that promote teaching excellence and support student learning campus-wide. A chemist by training, Frederick also leads the Summer Institutes on Scientific Teaching, a national training program for college science faculty.*

dents may be entirely absent among their less privileged peers. Truly equal access to computer science education, Margolis tells me, is "a civil rights issue for the 21st century."

Having documented the very unequal situation on the ground, she says, "we felt we had to do something about it." She and her colleagues thus created Exploring Computer Science (ECS), a university/K–12 partnership program that has developed an introductory curriculum for high school computer science students. ECS also offers professional development to teachers in the Los Angeles Unified School District—and now to nearly two dozen other districts nationwide. Participating teachers learn how to provide hands-on computer science instruction that is rigorous yet engaging, and they are joined with other teachers in an active and growing network. Whereas other organizations, among them Black Girls Code and Hack the Hood, focus their efforts outside of school time, such as during weekend workshops and summer boot camps, Margolis and her team are committed to serving underprivileged students in their schools, aware that financial and logistic barriers often prevent such students from taking advantage of extracurricular opportunities.

Nancy Se shares this commitment. Trained by Exploring Computer Science in 2013, she has since become an ECS "teacher leader," helping other teachers learn how to engage their students in computer science. Se teaches at Augustus F. Hawkins High School in South Los Angeles, where, in the 2013–2014 school year, 99 percent of the student body was African-American or Latino and 75 percent qualified as "economically disadvantaged," according to *U.S. News & World Report*. Se sees the challenges faced by the coding-for-all movement up close every day. "Many of my students don't have computers in their homes," she says. "Their only access to the Internet is through their phones, which they use for games and texting." Given this limited acquaintance with technology, her students have a lot of ground to cover—learning not only about the manifold functions of computers but also the behind-the-curtain reality that *people* design and program these machines. Most daunting of all, Se's students must overcome stereotypes about whom computer science is "for." "Working with computers, knowing how to code—this is foreign to the identities they've developed, even as students still in high school," Se notes. "In my classes, the students and I aren't just exploring an academic subject. We're reinventing their sense of themselves in the face of very powerful cultural messages."

Paging through essays written by her 12th graders, Se points to one in which a student expresses hope for a steady income for her and her baby. "Before taking a class in computer science, it never crossed my mind that I could be involved in or even major in that field," this student wrote. "As a single mother who wants to create the best future possible for my child, I also think it would be great to have a job doing what I love and [one that] provides financial stability." Writes another student: "Economic struggles have been around my whole life. Nonetheless, I refuse to let limited resources bring me down. On the contrary, they motivate me to utilize education as a path and guide me to life-long success. I yearn to one day possess the title of [a computer] animator with an average salary of $50,281 per year. I aspire to bring my current financial struggles to an end and take care of my family on my own."

Indeed, one of the rationales often cited for expanding coding instruction, especially in poor communities, is that a lack of programming knowledge will shut young people out of a lucrative industry. But many critics argue that a narrow focus on a technical skill such as coding is not a sustainable approach. Larry Cuban, a professor emeritus of education at Stanford University, points to the nation's experiment with the early computer language Logo in the 1970s and 1980s. Led by Massachusetts Institute of Technology professor Seymour Papert, the effort to teach students Logo flared and failed, Cuban says, because it did not teach the complex skills and rich knowledge that they need. He predicts that the same fate will befall the coding-for-all movement, which he believes is being urged on schools by business leaders with their own bottom lines in

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STUDENTS demonstrate an animation (*1*), storyboards (*2–3*) and artwork (*4*) for projects they are developing. Se says her students are doing more than programming: they are reinventing their sense of themselves.

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mind: it is a "tissue paper reform" that, "after one or two uses, shreds and is tossed away."

If instruction in coding is not the answer—or at least not all of it—then what is? Jeannette M. Wing believes she knows: computational thinking. Wing is a consulting professor of computer science at Carnegie Mellon University and a corporate vice president of Microsoft Research. In 2006 she published an article in an obscure journal that quickly became a classic. "Computational thinking is a fundamental skill for everyone, not just for computer scientists," she boldly declared. This mode of thinking, she went on to explain, "involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science."

"Computational thinking includes the ability to abstract, to engage in logical and symbolic reasoning, to take a big problem and decompose it into many smaller problems," Wing says. "These are skills that everyone can use, whether they're using a computer or not."

In her article, she wrote, "To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability." One of the educators who heard Wing's call was Aileen Owens. Owens used Wing's ideas to make computational thinking a key part of the curriculum at South Fayette Township School District, outside of Pittsburgh, where she is director of technology and innovation. In her view, instruction in computational thinking should begin early and grow progressively deeper and more complex through a series of graduated and interrelated projects.

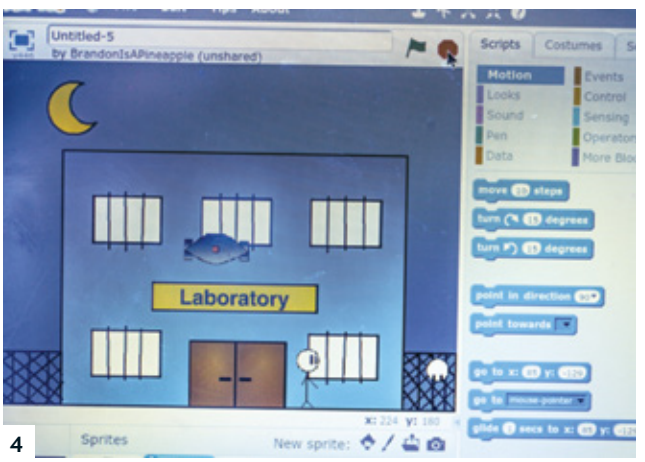
In South Fayette, students in kindergarten through second grade start learning the concepts behind programming by using what is known as a block-based coding program. In the program, called Scratch, they drag and drop blocks containing discrete commands: "Move 10 steps," "Wait 5 secs," "Turn left 90 degrees." By arranging these commands in a precise order, the students make things happen on their screens (a cartoon character advances, pauses, turns left) and begin to understand more generally how to give instructions to computers—instructions that become increasingly complex as they grow older. In grades three through five, students program motors and sensors and build Lego robots that move under their control. Computer-aided design (CAD) is taught in grades six through eight; students use CAD software to design their own inventions, and they prototype them by using a 3-D printer. By seventh grade, students have transitioned from block-based coding to text-based coding: writing code in the more complex but more flexible language employed by professional programmers.

"At every stage, the goal is to scaffold computational think-

ing so that each new level of understanding builds on the one that came before," Owens explains. "This is about much more than coding. This is about teaching habits of mind that can be used to solve problems in any realm—habits like breaking down a problem into its component parts, running small experiments to see which approaches fail and which succeed, and working together with other people to find and apply the best ideas." Using these strategies in a variety of settings shows students that computational thinking is useful well beyond the world of computers.

Even the very youngest children can learn such habits of mind. "We're teaching our kids to be problem solvers, to think logically, to engage in abstract thinking, to find patterns, to identify alternatives," says Melissa Unger, the science, technology, engineering, arts and mathematics (STEAM) teacher for kindergarten through second grade at South Fayette. "We start with questions like 'What are instructions? How do you give instructions so that a computer knows what you want it to do?' We have students 'program' their classmates, guiding them through a maze by holding up cards with arrows on them."

Like Los Altos, South Fayette is an affluent, highly educated community, home to professors from the area's many universities, as well as professionals who work in Pittsburgh's burgeoning tech sector. But computational thinking can be taught to all kinds of kids, as Excel Public Charter School in Kent, Wash., demonstrates. Excel enrolls a student body that is 37 percent African-American and 19 percent Latino; more than half its students qualify for free or reduced-price lunch. Although the school is located less than 20 miles from the Seattle area, home to tech giants Amazon and Microsoft, the students at Excel often feel cut off from the world of computers.



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Eli Sheldon, the school's computational thinking program manager, is aiming to change that. "I work with teachers to incorporate computational thinking into the subjects they teach, whether it's English, or math, or biology," Sheldon says. "Because students are encountering the same mental tools across many different courses, they come to see how universally applicable they are, even outside of school." Sheldon has collaborated with a math teacher to create a class unit on analyzing motion data from a professional basketball game and with a humanities teacher to develop interactive case studies drawn from the criminal justice system.

Proponents of the teaching of computational thinking believe it represents all the qualities that mere coding instruction lacks: a rich and deep intellectual discipline; a flexible set of mental tools that can be used in many and varied situations; and a body of knowledge and skills of genuine and lasting usefulness—in school, in the workplace and beyond.

Before arriving at Excel, Sheldon worked for four years as a program manager at Microsoft, where he saw computational thinking put to real-world use. "Over and over, I saw engineers take an incredibly complex problem and solve it using computational thinking," Sheldon recounts. "They were really good at breaking down the problem, putting the parts in logical order, testing one part at a time to see how that one small change affected the outcome. I watched them, and I thought, 'Everyone should know how to do that.'"

The nation's approach toward computer science education is still taking shape. As the assistant director for learning and innovation at the White House's Office of Science and Technology Policy, Kumar Garg is one of those steering the effort. He can point to some successes: "When President Obama took office, only 11 states allowed computer science courses to count toward graduation," Garg observes. "Since then, there's been a sea change: [28 states and Washington, D.C.] now allow computer science courses to be applied to math or science requirements." Garg also praises a "reboot" of the AP computer science course now under way at the College Board. The new course and exam will focus on both coding *and* computational thinking, an approach Garg endorses. "Students do need to learn the fundamentals of computer science, but coding is a way of helping students see what it's all for," he explains.

Under its Computer Science for All initiative, Garg notes, the Obama administration has asked school districts to submit five-year plans for expanding access to computer science instruction; districts with well-designed proposals will be granted funding for implementation. Of course, some schools are not waiting on the slow-grinding gears of the federal government to get started on innovating in computing education, whereas others have yet to even begin tackling the subject—a situation that calls to mind an aphorism attributed to science-fiction writer William Gibson, whose work explores the interactions between humans and technology. "The future is already here," Gibson is said to have observed. "It's just not evenly distributed yet." SA

MORE TO EXPLORE

Computational Thinking. Jeannette M. Wing in *Communications of the Association for Computing Machinery,* Vol. 49, No. 3, pages 33–35; March 2006.

Stuck in the Shallow End: Education, Race and Computing. Jane Margolis. MIT Press, 2008.

Learn about President Barack Obama's Computer Science for All initiative to empower a generation of American students with the computer science skills they need to thrive in a digital economy: www.whitehouse.gov/blog/2016/01/30/computer-science-all

FROM OUR ARCHIVES

Machine Learning. Seth Fletcher; August 2013.

BIOMECHANICS

THE SECRET TO SPEED

New insights into the biomechanics of sprinting could give athletes a leg up at the Olympics

By Dina Fine Maron

Photographs by Jeff Wilson

Dina Fine Maron is an associate editor at *Scientific American*.

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On a Friday morning this past February champion sprinter Mike Rodgers got strapped into a safety harness suspended from the ceiling above a custom-built treadmill. "No one's ever fallen, but you can be the first," he was told. Rodgers smirked and steeled himself to run. He was training for the Olympic trials. But that day he was not completing one of his standard, punishing drills on the track or in the weight room at his gym. Instead he had showed up at a small, white building in Dallas with "Locomotor Performance Laboratory" embossed on the door.

From the outside, the structure looks uninteresting, a converted printing shop across from a doggy day care and a yoga studio. But in recent years dozens of sprinters like Rodgers have been coming by this Southern Methodist University facility to get advice on their running technique from sports scientist Peter G. Weyand or to help him with his studies. Weyand has conducted what many researchers consider to be some of the best science to date on the biomechanics of sprinting and how these elite athletes achieve their record-breaking speeds. Ahead of the 2016 Summer Olympics in Rio de Janeiro, his findings have even been incorporated into training for top U.S. sprinters.

The heart of the operation is Weyand's treadmill, a roughly $250,000 contraption outfitted with specialized plates measuring the force that the runner exerts on the ground during locomotion. Three cameras positioned around the machine capture high-speed, 3-D images of the user's stride. Rodgers is hoping all these data will reveal insights that could help him make adjustments that would shave off crucial fractions of a second in the 100-meter dash.

Clad in the same type of shoes, spandex top and shorts, and reflective stickers Weyand asks all his subjects to wear, Rodgers starts to run, loping along at a little more than 6.5 miles an hour to warm up. Soon, however, he reaches more than 23 miles per hour. At this pace, the tattoo on his right calf—the cartoon Road Runner with the phrase "Catch me" inscribed below it—is a blur to the naked eye. The equipment feeds measurements into a specialized computer program that graphs his movements.

Weyand has studied more than 120 runners, including 12 other world-class sprinters—observations that have helped fill in a long-standing gap in scientists' understanding of the biomechanics of running at high speed. Before his investigations, the prevailing wisdom about great sprinters was that they are particularly adept at quickly repositioning their limbs for their next step while their feet are in the air. This claim stemmed largely from intuition rather than a theory based on evidence, however. Weyand was the first to test this idea scientifically—and his findings indicate that it is wrong. Instead the key to speed seems to be something else altogether, a factor that Weyand says he can teach sprinters to improve.

ON YOUR MARK

ALTHOUGH RUNNING as a sport dates back to at least 776 B.C., when a footrace was the only event in the earliest Olympic Games, the science underpinning it has long lagged far behind. Perhaps the earliest attempt to obtain rigorous data on runners came from British Nobelist Archibald Hill, who in 1927 conducted an experiment in which runners wearing magnets sprinted past large coils of wire that detected the magnets. Knowing the distance between wire coils, he could calculate the velocity and acceleration of the passing runners.

The invention of modern force plates in the 1950s provided the means to study another aspect of running. These devices, which resemble scales, record the amount of weight applied to

IN BRIEF

Conventional wisdom about what makes a top sprinter said that the athlete repositions his or her limbs in midair for the next step faster than other runners. **The latest findings** indicate that, in fact, the force with which elite sprinters hit the ground plays a key role in their performance. **Biomechanical analyses** have revealed the factors that contribute to force and how sprinters can augment them to achieve higher running speeds.

DATA IN MOTION: Researchers at Southern Methodist University prepare American elite sprinter Mike Rodgers to run in their laboratory (*1*). To help track his movements, Andrew Udofa, a doctoral student, places reflective stickers on Rodgers's leg (*2*). A runner's data are automatically fed into computer programs that will help the Southern Methodist team dissect his stride (*3*).

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them and measure it over the course of a stride. With such tools, scientists can examine the changing force exerted by a runner at different speeds during a race or compare the forces from different types of footfalls—those of runners who strike with their heel first versus those who strike toe first, for instance. Italian scientist Giovanni Cavagna gathered force data on runners in the 1970s by having them run over plates set up on a track. But because the plates are so expensive, he had just a few of them—enough to capture data from just a small fraction of a race. To obtain a complete run, Cavagna had to hold multiple races and manually move the plates forward after each one, recording only a few of the runners' steps at a time, which he then cobbled together into a composite picture.

Based on those and other early studies, sprinting science focused primarily on what slows runners down—air resistance, says animal locomotion expert Jim Usherwood of the University of London—as opposed to what speeds them up. On the whole, the work shed little light on what sprinters could do to boost their performance.

Weyand's research has helped shift that focus and generated insights that athletes can act on. But he is not the first to envision such advances. Because speed is the product of stride length times stride frequency, runners presumed that cutting down the amount of time each foot spends on the ground would net greater speed. In 2000 Weyand and his colleagues published a landmark paper showing how it is actually done. They enlisted 33 runners of varying abilities to run on an earlier iteration of their force-plate-equipped treadmill. The results proved surprising. Weyand expected that the feet of faster runners would spend less time on the ground and hence more time in the air than the feet of their slower counterparts. But he did not foresee that regardless of the runners' abilities, they would all take the same amount of time between when a foot lifted off the ground and when that same foot made contact for its next step.

What actually set the great sprinters apart from the rest, Weyand's team discovered, was the force with which the runners hit the ground. In subsequent work, Weyand further determined that at top speeds the best runners landed with a peak force up to five times their body weight, compared with 3.5 times among the average runners. That difference is significant because like a superball that bounces higher the harder it is thrown, a runner who hits the ground with greater force stores up more energy at impact and will travel forward farther and faster as a result, with longer strides. Forceful hits also allow runners to rebound more quickly, reducing the time that feet are touching the ground and thus increasing stride frequency. The best runners have longer, more frequent strides.

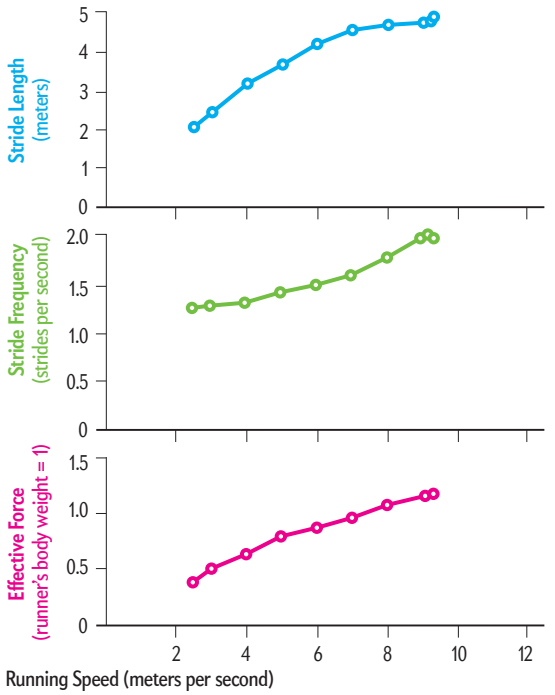
GET SET

RECENTLY WEYAND'S TEAM additionally figured out how the best sprinters are able to generate those higher forces—and in so doing forced a revision of another central tenet of the running world. According to the popular so-called spring-mass model of running mechanics put forward in the late 1980s, the legs of runners move relatively passively, working like pogo sticks to catch the body on hitting the ground and then pushing the body back into the air on rebounding. Graphical representations of the force of their footfall resemble a gentle, symmetrical curve.

But the model is based on observations of runners moving at slower speeds. When Weyand, Southern Methodist physicist Laurence Ryan and biomechanics expert Ken Clark, now at

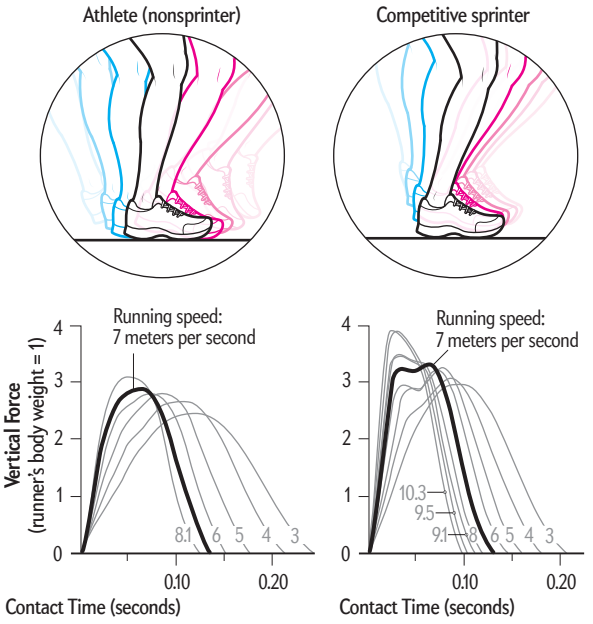
Gaining Ground

What does it take to be an elite sprinter? Superb genetics and strength training play a part, but they are not the only elements of speed. In recent years studies carried out using state-of-the-art technology have yielded fresh insights into the biomechanics of sprinting that can help both professional sprinters and amateurs slash their race times.



Force Is a Key Factor

Scientists have long known that increases in stride length and stride frequency lead to faster running speeds (*top* and *middle*). In 2000 Peter G. Weyand of Southern Methodist and his team proved that the fastest runners also hit the ground with the most force (*bottom*). Force, it turns out, is what drives stride length and frequency.



Form Affects Force

The legs of average runners move passively like pogo sticks as they hit the ground and rebound into the air. When represented in a graph that plots force against time in contact with the ground, the result is a gentle curve (*left*). In 2014 Weyand's team showed that the legs of elite sprinters, in contrast, work like pistons to deliver more forceful hits that make quicker contact with the ground. Their movements produce a correspondingly sharper curve when graphed (*right*). To punch the ground so forcefully, sprinters must keep their ankles stiff—loose ankles weaken the rebound because they absorb some of the force at impact.

West Chester University, analyzed their video footage and force data, they noticed that the model did not seem to hold for the fastest runners. Instead of contracting and expanding smoothly like pogo stick springs, their legs operated more like pistons, delivering abrupt, intense hits. Force data from their footfall made a tight, tall peak.

Careful study of the lower limbs of these fast runners revealed subtle factors that contribute to the elevated forces they generate: they stiffen the ankle right before they hit the ground, which serves to decelerate the foot and ankle fractions of a second after impact. This deceleration helps to maximize the force exerted on the body by the ground in response to impact and to prevent the loss of that force. Elite sprinters also keep their knees high, maximizing their distance from the ground, which gives them time and space to accelerate their footfall and ultimately land with greater force. The findings, published in 2014, make sense logically, Weyand says: if you hit someone with a limp wrist, it will not have as much force. Yet if you keep your wrist stiff, then you will pack a better punch, he observes.

Those insights are now informing what the team says to runners and coaches who seek their advice on how to boost sprinting performance. "It's about simple cues. We don't say, decelerate yourself—we say, stay stiff into the ground, and then deceleration will happen because of that," Weyand says. A runner who heeds this advice will feel a harder hit to the ground with each footfall, he adds. The comportment of the rest of the body is also important, including the ankles, knees, hips, torso and head, which should also be kept stiff.

Weyand's findings have not surprised everyone. Biomechanist Ralph Mann, a former Olympic hurdler who now works with runners and coaches at USA Track & Field, had already been giving that type of feedback to runners, says USA Track & Field coach Darryl Woodson, who coaches eight sprinters, including Rodgers. Woodson says having concrete data supporting Mann's advice, however, made coaches "feel more confident in what they told runners."

SOURCES: "ARE RUNNING SPEEDS MAXIMIZED WITH SIMPLE-SPRING STANCE MECHANICS?" BY KENNETH P. CLARK AND PETER G. WEYAND, IN *JOURNAL OF APPLIED PHYSIOLOGY*, VOL. 117, NO. 6: SEPTEMBER 15, 2014 (*bottom right*); "FASTER TOP RUNNING SPEEDS ARE ACHIEVED WITH GREATER GROUND FORCES NOT MORE RAPID LEG MOVEMENTS." BY PETER G. WEYAND ET AL., IN *JOURNAL OF APPLIED PHYSIOLOGY*, VOL. 89, NO. 5: NOVEMBER 1, 2000 (*left*)

SCIENTIFIC AMERICAN ONLINE Watch video of sprinting science in Peter G. Weyand's laboratory at ScientificAmerican.com/aug2016/sprinting

Graphics by Jen Christiansen, Illustration by Brown Bird Design

DECONSTRUCTING SPEED: Biomechanics expert Weyand has spent two decades trying to form a better understanding of what makes elite sprinters so fast.

GO!

ELITE ATHLETES WHO HAVE TAKEN Weyand's tutelage to heart report improvement. Olympic hurdler David Oliver wanted to enhance his performance after he took home the bronze in his event in 2008, so his strengthening coach brought him to Weyand in 2012. Weyand pinpointed Oliver's two weak areas: his feet hit too far from his center of mass, and his knees were too far back—instead of parallel with or ahead of the alternate knee—which limited the force of his hits. Oliver says he focused on those problems in his training and strengthening exercises and saw a consistent improvement after several months. He went on to win the gold medal at a world championship event held in Moscow the following year in the 110-meter hurdles, and he is still fourth on the all-time-greatest list for that event.

But anecdotal reports notwithstanding, no scientific studies on these runners after they have attempted to follow Weyand's advice have been published to date. One analysis currently under way suggests that his recommendations can bring significant benefits, however. Matt Bundle of the University of Montana has been analyzing how the pointers affect volunteer sprinters and has found improvements "on the order of the bump we think people get from performance-enhancing drugs," he says. "It's a pretty dramatic augmentation."

Still, Weyand acknowledges that biomechanics are not the whole story. There are still many areas left to study and things outside of a runner's control, he says. Genetics, for example, are clearly very important. "If you don't have a decent build and

> Instead of contracting and expanding smoothly like pogo stick springs, the runners' legs operated more like pistons.

muscle properties that will allow you to be forceful, you won't get [great sprinting] done," Weyand explains. And sometimes an athlete can compensate for biomechanical shortcomings: the fastest person ever timed, Usain Bolt of Jamaica, does not execute all his mechanics flawlessly, according to Weyand. That not quite perfect form suggests that other factors must help Bolt's game—especially his height and strength.

Sports scientists observe that Weyand's discoveries apply not just to elite athletes but also to recreational sprinters. Maintaining a stiff ankle, getting knees higher and trying to hit the ground with great force will not make most people Olympians but could help get them to a personal best, they say. Of course, hitting the ground so hard could be problematic for a recreational runner. If a person has poor form, for example, such blows could boost chances of potential injuries, including knee pain, arch pain, shin splints or a condition known as metatarsalgia, in which the ball of the foot becomes inflamed. French researcher JB Morin of the University of Nice Sophia Antipolis recommends running downhill as part of a training regimen designed to keep ankles straight. He also suggests jumping rope to help with quick rebounding. (Weyand's findings apply exclusively to sprinters. Endurance runners cannot hit the ground with as much force, because they instead need to preserve their energy over a longer time.)

For his part, Rodgers is getting good news from Weyand. In general, the best sprinters "attack the ground," according to the sports scientist. Rodgers's force data demonstrated that he already does exactly that. Although he weighs only about 165 pounds, he hit the treadmill with more than 700 pounds of force—and that was when his muscles were tired from a prior workout. There are no guarantees at the Olympics, but if Rodgers qualifies to compete, his assessment bodes well for race day. SA

MORE TO EXPLORE

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Chiara Zuccato is a professor in the department of biosciences at the University of Milan in Italy. She studies the pathogenic mechanisms of Huntington's disease.

Elena Cattaneo is a professor of pharmacology in the University of Milan's department of biosciences. She is also a senator with lifelong tenure in the Italian parliament. For more than 20 years Cattaneo's laboratory has been studying Huntington's and seeking therapies for it. The authors dedicate this article to their students and to Huntington's sufferers and their families.

EVOLUTION

The Huntington's PARADOX

The gene that causes a devastating neurodegenerative disease may also have been critical in the evolution of our species

By Chiara Zuccato and Elena Cattaneo

IN BRIEF

Huntington's disease, a serious genetic disorder affecting the brain, is caused by a mutation in which some genetic code letters of a person's DNA are repeated too many times.

Studies have now reconstructed the evolutionary history of the affected gene, which first appeared more than a billion years ago and still can be found in most species today.

The disease may be an unfortunate by-product of an evolutionary process. Expanding numbers of the code letters in the gene appear to assist in nervous system development.

Repeated code letters may increase over many generations. An individual who has a certain number of repeats develops the uncontrolled movements of Huntington's.

Illustration by Andrea Ucini

FOR 15 YEARS BRITISH INSURERS HAVE AGREED NOT to use information about a prospective policyholder's genes to determine eligibility for certain life insurance policies. The moratorium has one critical exception. An underwriter can take into account when writing some policies whether a person carries the gene for the malady once known as chronic hereditary chorea and now simply Huntington's disease.

Becoming aware of a positive gene test lets insurers know that, in the continuing absence of any intervention, the applicant's cause of death will likely be Huntington's—knowledge that comes with far greater certainty than other factors they typically consider, such as smoking, drinking or riding a motorcycle. Someone with the errant gene may begin to experience mood shifts and memory disturbances right in the prime of life, usually between the ages of 30 and 50, although these changes can occur later. Then the symptoms will worsen, expanding to include uncontrollable movements and spasms and an unstable walk often described as a halting "dance." Little by little, the body will lose all its functions, slowing down until complete immobility sets in, and the person finally succumbs to the disease.

Researchers have understood for many years that an aberration of the gene known as *huntingtin* causes the condition. All humans carry *huntingtin* because it is important in the development of the nervous system before birth. But the gene differs slightly from person to person, and these differences explain why some become ill and others stay healthy.

One section of the gene contains a triplet of nucleotides, or "DNA code letters"—namely, C-A-G—that repeats multiple times in a row. In people who remain healthy, the number of CAG triplets ranges between eight and 35. If the number is higher, an individual will eventually sicken with the disease, named after George Huntington (1850–1916), the physician who first described it. One bad gene copy (of the two *huntingtin* genes that each of us inherits from our parents) is sufficient to cause the disorder, and each child of an affected parent has a high—50 percent—chance of carrying the gene. As a consequence of this inheritance pattern, one in 10,000 individuals in Europe and America is afflicted.

Investigators have also known that Huntington's symptoms result from the death of neurons in the corpus striatum and the cortex, areas of the brain that control body movements and higher cognitive functions. Consequently, a good deal of the research into the disorder aims to identify how the high-repeat versions of the gene cause such damage and to develop drugs that can halt the relentless progression of symptoms.

Our laboratory, along with many others in various countries, devotes much energy to these efforts. Several years ago in the course of that research, a number of us became intrigued as well by the broader question of why harmful versions of the gene persist generation after generation instead of being weeded out by natural selection. We wondered whether a biological game of brinkmanship is at work. Is there some survival or reproductive benefit to our species in having large numbers of genetic repeats but perhaps not too many? People suffering from the disease also ask this question; they understand that the answer will probably not cure anyone, yet they still want to know.

Recently investigations into this puzzle have led to intriguing insights into the gene's role in the development of the nervous system in humans and other organisms. It turns out that an increasing number of CAG repeats appears to promote the functioning of neurons, as long as the rise does not surpass the disease threshold. In this sense, Huntington's may be less of a genetic disorder than an unfortunate by-product of a brain-shaping evolutionary process gone awry. A genetic change that might make us "smarter" appears to lead to tragic consequences if pushed too far. Therein lies the paradox of Huntington's.

IN THE BEGINNING

DETECTIVE WORK THAT LED to our current understanding of the part the gene plays in the evolution of the nervous system required researchers to peer back more than a billion years to the advent of the ancestors of both humans and a multicellular amoeba called *Dictyostelium discoideum*. These early life-forms lived between the Paleoproterozoic and the Mesoproterozoic eras and were the first to carry the gene, though in a form that was slightly different from the human version.

Descendants of *D. discoideum* amoebas can still be found living in soil and decaying leaves on the forest floor and feeding on bacteria. They allowed Miguel Andrade-Navarro, then at the Max Delbrück Center for Molecular Medicine in Berlin, and his group to search complex databases and find the gene in the amoeba in 2009. Andrade-Navarro and his collaborators discovered that one of the ways the amoeba's Huntington's gene (a less formal name for *huntingtin*) differs from the human kind is that it possesses no CAG triplets. Nevertheless, the gene

appears to take on a critical part in one stage of the organism's life by letting single-celled amoebae join up with others to form a multicellular entity called a pseudoplasmodium.

This conglomeration of amoebae fends for itself better than a single amoeba when food is scarce or environmental conditions are otherwise harsh. In 2011 Michael Myre and James Gusella of Massachusetts General Hospital reported that the gene regulates a number of vital cellular processes, including the transition of *Dictyostelium* to its multicellular stage. Individual cells lacking the Huntington's gene move about with difficulty and are unable to aggregate normally with other cells. The gene thus appears key to cells that need to "socialize" with one another to survive.

In fact, the gene has many functions. A team at Johns Hopkins University has discovered that it controls when amoebae reproduce and regulates their response to stimuli from their surroundings that impel them to move toward food. In our lab we found that the *Dictyostelium* version of the gene protects mammalian cells from stimuli that trigger cell death.

The amoeba preceded the division of the tree of life into its two branches more than 550 million years ago: the protostomes, which include insects, crustaceans, mollusks, and the deuterostomes, which led to the first vertebrates—the fishes, birds, amphibians, reptiles, mammals, primates and modern human beings. Only the deuterostomes went on to accumulate CAG triplets at the place in the gene where the disease-causing mutation in humans is found.

As we discovered in 2008, the Huntington's gene starts to acquire CAG triplets in a category of basal deuterostomes called echinoderms (such as the sea urchin *Strongylocentrotus purpuratus*). Working with a group of scientists at our university in Milan who specialize in computing techniques for biology, we deciphered the DNA sequence of the sea urchin gene, identifying two CAG triplets in the initial part of the gene.

In this creature, the DNA sequence still differs from that of the human gene. Despite the presence of a primitive nervous system in sea urchins, the gene is present mainly in nonneural tissues. Its absence suggests that early on in evolution, the gene and its two CAG triplets did not have an important function in the nervous system. Research on the triplets in protostomes is still in relatively early stages, but it is clear that they occur only rarely (for example, bees have a single CAG). In most cases, these animal phyla do not carry any CAG in their Huntington's gene.

In the late 2000s our lab analyzed the DNA sequences in the Huntington's gene of other deuterostomes—the most surprising of which was the sequence from the amphioxus, or lancelet, of the Cephalochordata family (which we worked out with Mario Pestarinos's group at the University of Genoa in Italy). The biology of the lancelet, a small, fishlike creature, marks a pivotal development in the evolution of the nervous system—the acquisition of a polarized neural structure extending from front to back in the animal. The front end of this nerve cord in the amphioxus is slightly differentiated to form a sac, or vesicle, which appears to be an early precursor of a primitive brain.

The sequence showed that, as for sea urchins, two CAG triplets occur together. In this case, however, the sequence of genetic letters around the triplet pair was similar to that in vertebrates, including humans, and the protein encoded by the gene was largely confined to neural tissue, allowing us to speculate that this difference might have helped form the primitive brain, with its front-to-back structure.

When researchers then inspected the genomes of vertebrates, they found that CAG triplets begin to lengthen

LAB NOTES

Evolutionary Bequest

An experiment fast-forwards through millions of years of evolution

We have learned from recent experiments that CAG repeats in the Huntington's gene appear to influence the way the nervous system evolved in vertebrates and that more triplets enable a more elaborate early life development process to occur.

In our studies, we looked at the gene's effect on structures called neural rosettes, which arise when cells from the embryo are cultured in a laboratory dish. We re-created the process by working with stem cells taken from early mouse embryos. These embryonic stem cells have the ability to differentiate into other cell types. If the stem cells are treated with molecules known to guide the development of the nervous system, they become what are called neuroepithelial cells arranged around a central cavity in a pattern that resembles a flower—neural rosettes. These rosettes mimic development of the neural tube in the embryo, a structure from which the central nervous system is formed.

First, we showed that the Huntington's gene is important to the rosettes. We found that it allows the cells in the rosettes to adhere to one another. Stem cells deprived of a healthy Huntington's gene did not form the flowerlike structures. In fact, in the absence of the healthy gene, an enzyme cuts the adhesion protein on the cell membrane, preventing the cells from attaching. If the Huntington's gene was restored, rosettes started to form.

Next we asked what would happen if we removed the original gene from a mouse stem cell and replaced it with a gene from the amoeba (no CAGs), amphioxus (two), fish (four) and humans (15), among others? Differences in rosette development suggest whether progressively higher numbers of CAG repeats may render the Huntington's gene more able to help in the formation of the nervous system in these species.

The genes of less complex species, such as the amoeba, did not produce rosettes. The first recognizable structure, albeit incomplete, occurred after inserting the amphioxus gene. In general, genes with more CAGs resulted in better formed and larger rosettes with a large central cavity. The Huntington's gene from fish induced the formation of beautiful rosettes—bigger structures composed of many more cells than those induced by the amphioxus gene. The human gene—the one with the longest number of repeats—yielded the best results, with the largest and best-structured rosettes.

Together the results offer a synopsis of what may have occurred over millions of years of evolution.

—*C.Z.* and *E.C.*

appreciably in organisms with more sophisticated nervous systems until they reach their maximum extension in humans. This can be inferred by looking at species progressively more distant from humans such as cattle (15 CAGs), pigs (18), dogs (10), mice (seven) and opossums (six). Many organisms, including primates, have CAG segments that differ in length among individuals of the same species.

Vertebrates mark a new chapter in neural evolution. Their brain develops from a hollow structure called the neural tube that forms in the embryo and later develops into a brain. In 1997 the group led by Marcy MacDonald of Massachusetts General found that the Huntington's gene is involved in neural tube formation, and in 2012 our team confirmed and extended this finding by showing that it contributes to the development of a neural tube–like structure in a culture dish.

HUMAN TRIPLETS

IN THE MEANTIME, other lines of research began to sketch out yet another role for CAG repeats: improving the mind. These discoveries grew in part out of efforts beginning in the 1970s to look for the gene. Finally, in 1993 geneticist Nancy Wexler and 57 other researchers, all in the Huntington's Disease Collaborative Research Group, isolated and sequenced the human gene, which sits on chromosome 4, thereby paving the way for the discovery that the number of CAG triplets is 36 or more in people with Huntington's.

A year later David C. Rubinsztein, a geneticist now at the University of Cambridge, published a paper suggesting that the CAG section in the Huntington's gene in healthy individuals has a tendency to expand as it is passed on to one's offspring. Also in 1994 Max Perutz, a Cambridge Nobelist, found that glutamine—the amino acid, or protein-building block, encoded by the CAG genetic letters—promotes binding to other proteins. These results, however, were followed by a long lull in research into nonpathological functions of CAG repeats. At the time, CAGs and other duplicated sequences were viewed as genetic "junk," with potentially no purpose.

In 2008 John W. Fondon III, now at the University of Texas at Arlington, and David King of Southern Illinois University Carbondale infused new interest in the question by speculating both that triplet nucleotides might be involved in the development and evolution of the nervous system and that an expansion of the CAG triplet in brain cells may enhance cognition and the capacity for sexual and other forms of social interaction.

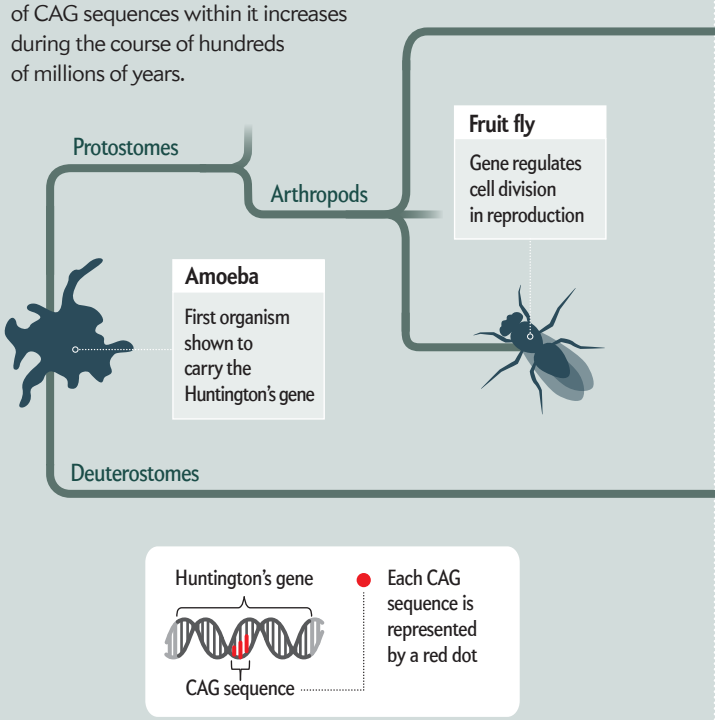
Since then, experimental evidence has mounted in support of these conjectures. According to a study conducted by Michael Hayden's team at the University of British Columbia in Vancouver, one individual in 17 carries an "intermediate allele"—a healthy Huntington's gene with CAGs totaling between 27 and 35 repeats, a high but not pathological number. Healthy people with a high number of CAG triplets tend to have more gray matter (neurons) in the globus pallidus, a brain area that governs the planning and control of movement and is involved in higher-level cognitive processes. In petri dish studies of brain cells, our lab has also shown that more triplets lead to more sophisticated nervous system–like structures [*see box on preceding page*].

Even carriers of the gene who are destined to become ill demonstrate high levels of cognitive functioning. In 2012 Carsten Saft and Christian Beste, both then at Ruhr University Bochum in Germany, reported that those with gene variants that lead to the disease who have not yet developed symptoms achieve better scores in visual and other perceptual tests than people with normal variants.

A TREE OF LIFE

Biography of a Gene

What do we owe to the lowly amoeba? One hand-me-down bequeathed over the eons is the Huntington's gene—the same one that, in its aberrant form, is responsible for Huntington's disease in humans. The unmutated gene appears to contribute to development in early life and to building complex nervous systems. Its story, traced on a tree of life, documents an ever expanding number of biological roles for the gene as the number of CAG sequences within it increases during the course of hundreds of millions of years.

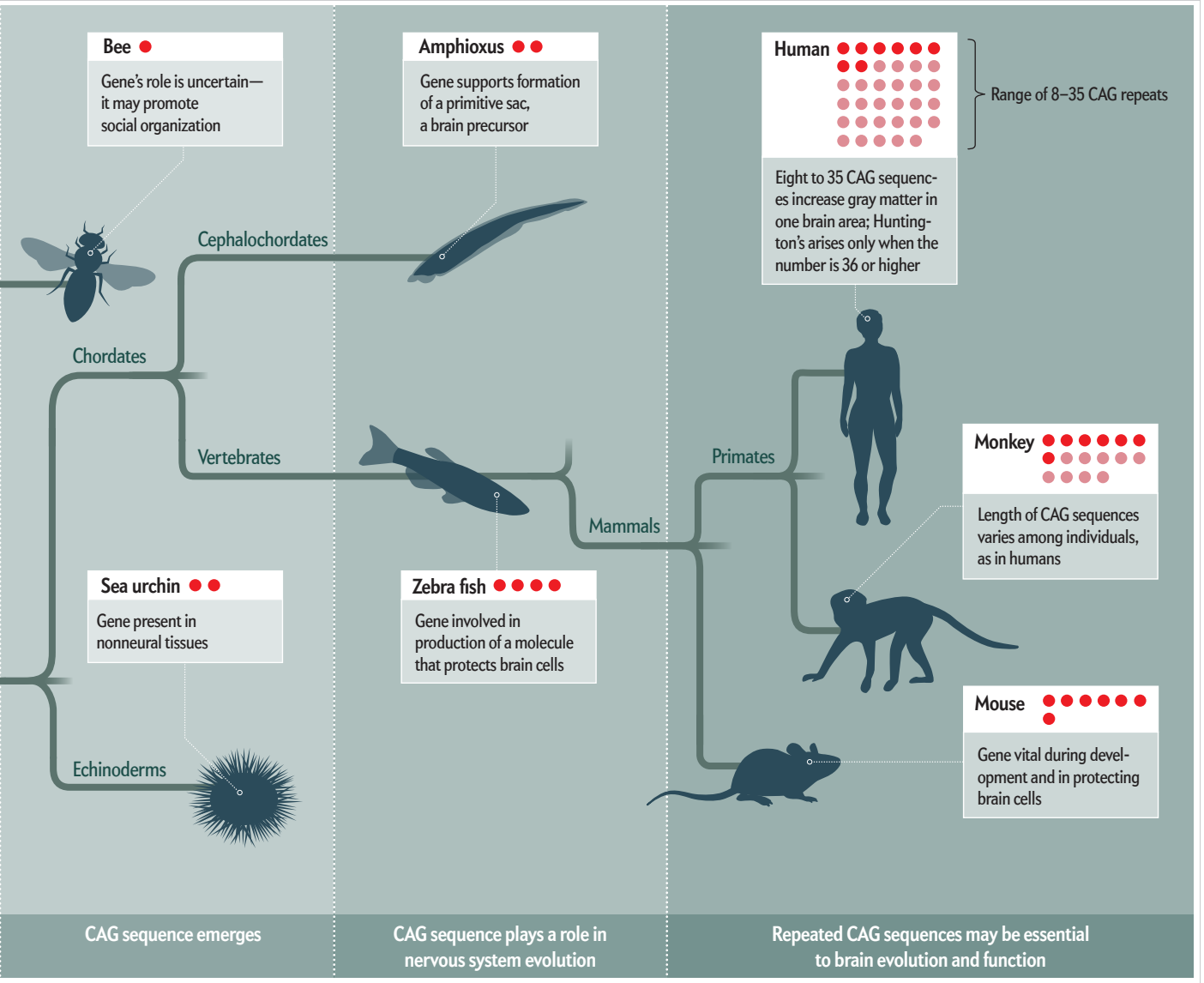


Huntington's gene is present without CAG sequences

A BRAIN HELPER

NEW RESEARCH ON the Huntington's gene has also delved into which specific tasks the gene carries out in the brain. In our research using brain cells in a lab dish, we found that the healthy form of the gene makes neurons hardier and more resistant to stress. Conversely, other researchers found that turning the gene off in the brain of mice causes cells to die and neurological symptoms to appear similar to those seen in mice carrying a harmful version of the Huntington's gene. We have also demonstrated that the gene stimulates the production of brain-derived neurotrophic factor, a protein that promotes the formation of brain circuits and the transmission of nerve signals.

SCIENTIFIC AMERICAN ONLINE Watch Cattaneo describe stem cell therapy for Huntington's disease at ScientificAmerican.com/aug2016/huntingtons



Perhaps most important, the Huntington's gene is in its most active state during early embryonic development. Quite simply, without it, we would not have been born. The gene goes to work during gastrulation, the stage of embryonic development from which the main body tissues develop. Later on, the gene regulates the formation of new neurons and helps to connect them.

Despite the progress made, the paradox of Huntington's persists. Acquiring a CAG tract that continuously extends itself is perhaps the major evolutionary achievement of the Huntington's gene, but the tendency to expand also poses a terrible risk of a devastating disease. Puzzles surrounding the gene's repeating genetic segments will occupy neuroscientists for years to come. We still need a better understanding of why the CAG triplets in the gene vary so much in length. What changes occur in the brain when the number of CAG triplets nears the threshold that will result in a diagnosis of Huntington's? Why does the gene suddenly become harmful at 36 repetitions? Understanding that the Huntington's gene is both a boon and a bane may help allay some of the stigma of the disease, letting it be viewed not as a genetic defect but as an offshoot of a biological process that ultimately made us the human beings we are. SA

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scientificamerican.com/magazine/sa

Graphic by Amanda Montañez

THE SEVEN-YEAR MISSION TO FETCH 60 GRAMS OF ASTEROID

PLANETARY SCIENCE

The OSIRIS-REx probe's journey to the asteroid Bennu will answer questions about our deepest past and possible futures

By Dante S. Lauretta

IN BRIEF

Asteroids are pristine remnants from the birth of the solar system that offer answers to lingering questions about planet formation and perhaps even the origins of life.

They pose opportunities as well as hazards: asteroids contain metals, water and organic compounds that could be mined. But a small number of them also have the potential to strike Earth.

Whether for science, security or profit, gathering samples from asteroids and bringing them back to our planet for further study is the next frontier in asteroid research.

Illustration by Bryan Christie

LIKE A HUMMINGBIRD hovering over a flower, the OSIRIS-REx spacecraft will attempt to retrieve samples from Bennu's carbon-rich surface in 2019. The mission is the most ambitious asteroid-sample return ever attempted—and the U.S.'s first.

Dante S. Lauretta is a professor of planetary science at the University of Arizona. His primary research interests include the formation of habitable planets and the likelihood of life originating elsewhere in the universe. He enjoys mountain biking with his family in the natural beauty of the Sonoran Desert he calls home.

WHAT MAY BE THE MOST THREATENING ASTEROID KNOWN to humankind was discovered in 1999, tumbling through space on an unstable orbit that periodically intersects that of Earth around the sun. Astronomers eventually named the half-kilometer-wide object Bennu, after a creation god from Egyptian mythology. And indeed, if Bennu, filled with organic compounds and water-rich minerals, fell on a barren world, it might sow the seeds of life. Instead it may be destined to cause immense suffering and death. Astronomers have projected that in 2135, Bennu will pass nearer to Earth than the moon, in a flyby that could tweak the asteroid's trajectory to guarantee a strike on our planet in the late 22nd century.

No one can predict where exactly on Earth Bennu might fall, although basic arithmetic shows its impact could release as much energy as 3,000 megatons of TNT. If its 2135 flyby sets it on a collision course with Earth, global leaders would basically have two options to avert disaster: either evacuate large regions of the world or launch a mission to deflect the asteroid. To know just how big an evacuation or a deflection mission would need to be, those future planners would rely in part on data gathered more than a century earlier, by a NASA spacecraft launching this September. Called OSIRIS-REx, this spacecraft will visit Bennu with the objective of returning to Earth carrying samples of the asteroid.

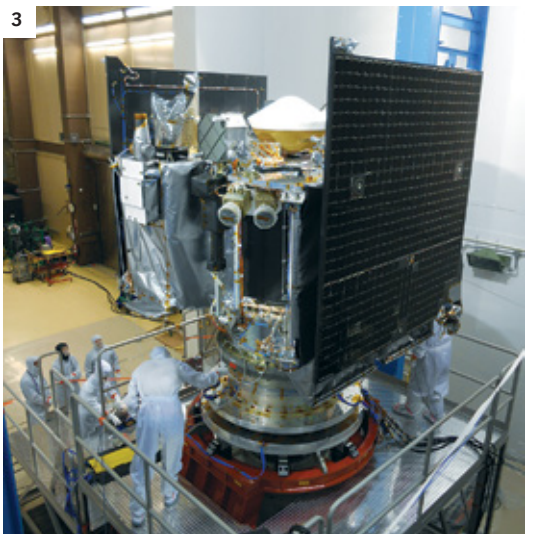
THE ORIGINS OF OSIRIS-REX

AS LEFTOVERS FROM THE FORMATION of the solar system, asteroids are emissaries from the darkest depths of our history, carrying otherwise unobtainable data about events that predate Earth's geologic record by hundreds of millions of years. Samples from an asteroid might contain answers to lingering questions about the birth of the sun, the formation of planets and even the origins of life on Earth. Add to all of this the need to guard against cataclysmic asteroid strikes, and it is obvious why scientists are interested in these objects.

It is less obvious why we need to send a probe on a round-trip mission to get samples. After all, pieces of asteroids fall to Earth all the time—we call them meteorites. The problem is that few if any meteorites are pristine. All must endure a fiery, surface-melting entry into Earth's atmosphere, and most languish for years, centuries or millennia before being found, their untold stories slowly fading from extended exposure to wind and rain. Most asteroids, in contrast, have been effectively held in stasis for billions of years in the sterile environment of deep space. Visiting them is the only way to access the information they contain.

And among asteroids, Bennu is a special case. Most of the meteoritic fragments that fill Earth's museums are composed of rock and metal—materials durable enough to survive the fall to our planet's surface. Bennu, on the other hand, is a coal-black mass of delicate organic compounds. Such carbonaceous compounds could be precursors to our planet's carbon-based biochemistry. Even if Bennu were not potentially hazardous, scientists would want to study it. But potentially hazardous it is—and it is precisely *because* Bennu comes so perilously close to our planet that a sample-return mission is feasible.

Bennu's tale traces back at least a billion years, when it was born as a rubble pile ejected from an impact-shattered protoplanet drifting between Mars and Jupiter. The story of OSIRIS-REx only begins in February 2004, when I was a third-year assistant professor working at the Lunar and Planetary Laboratory at the University of Arizona. The aerospace company Lockheed Martin approached my boss, Michael J. Drake, to be the principal investigator on a proposed NASA asteroid-sample-return mission, and Drake approached me to be his deputy.



OSIRIS-REX'S JOURNEY to Bennu began 12 years before its scheduled September 2016 launch. The spacecraft was first assembled (*1*) and later tested in vacuum chambers (*2*) and acoustics laboratories (*3*) at Lockheed Martin's Space Systems facility in Littleton, Colo.

COURTESY OF LOCKHEED MARTIN CORPORATION (*top two*); COURTESY OF SYMEON PLATTS *University of Arizona* (*bottom*)

My early work on the mission was to define its scientific rationale. I had been studying meteorites for more than a decade and knew all the unanswered questions about them that only a sizable sample return of pristine material could provide. At the time, just one other project was comparable to ours: the Japan Aerospace Exploration Agency's Hayabusa mission, which rendezvoused with the asteroid Itokawa to gather samples in 2005. Hayabusa was only partially successful. The probe managed to gather 1,500 microscopic mineral grains, much fewer than expected. (Getting samples from an asteroid is hard!) Additionally, Itokawa was a bright, stony object, with a very different history and scientific potential from dark, carbonaceous asteroids such as Bennu. We were entering new territory.

At home one evening, I decided to draft an outline of the mission's major scientific themes and wrote down four words: origins, spectroscopy, resources and security. Pristine samples from an asteroid such as Bennu could tell us more about the origins of planets and even of life itself. Spectroscopic studies of its surface soil—the regolith—would increase the chance of successfully collecting a scientifically useful sample and could also reveal whether Bennu possesses valuable resources that could someday be mined. The more we could learn about Bennu's orbit, composition and other characteristics, the better our chances of determining whether the asteroid would pose a threat to Earth—and how we might deflect it. More broadly, the high-fidelity "ground truth" data from a spacecraft sent to Bennu would allow us to pinpoint and control for flaws that might exist in telescopic observations and theoretical models, bolstering studies of the wider variety of asteroids across the solar system.

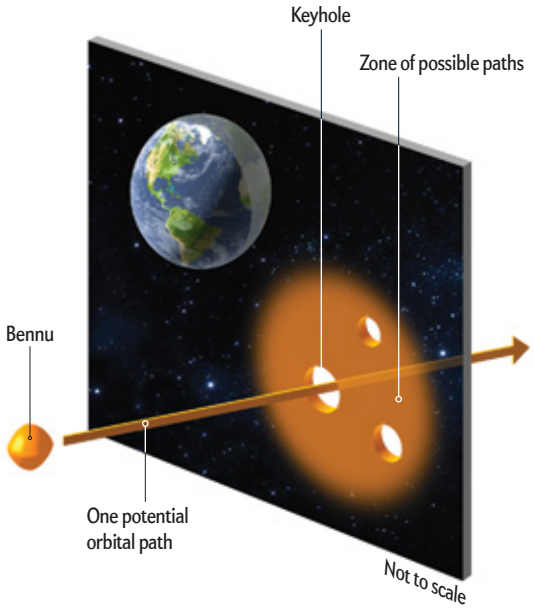
That outline came to define the mission and provided its awesomely convoluted acronym: OSIRIS-REx stands for Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer. NASA selected OSIRIS-REx for flight on May 25, 2011, and the team gathered to celebrate our success. Unfortunately, Drake passed away shortly thereafter, in September 2011. I was promoted from deputy to replace him as principal investigator. The OSIRIS-REx team works every day in Mike's honor, knowing that he would be proud of us as we prepare to open a new scientific frontier.

FROM LIFE'S ORIGINS TO OFF-WORLD ECONOMIES

OSIRIS-REX'S JOURNEY will begin when the spacecraft launches from Cape Canaveral, Fla., on an Atlas V rocket in September. It will travel across the solar system for nearly two years before arriving at Bennu in August 2018. It will then orbit Bennu for more than three years, thoroughly mapping the asteroid and ultimately collecting a sample weighing at least 60 grams.

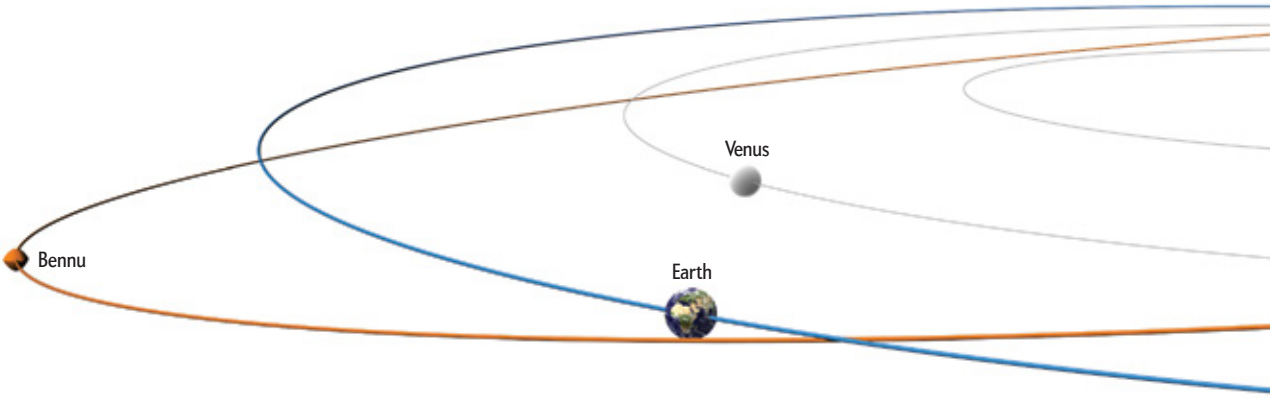
Up Close to an Ominous Asteroid

In September, NASA's OSIRIS-REx spacecraft will embark on an interplanetary voyage to Bennu, a 0.5-kilometer-wide near-Earth asteroid that could someday strike our planet 1. By clarifying the sources of instabilities in Bennu's orbit, OSIRIS-REx could reveal important details about the future, such as whether the asteroid will, in fact, ever hit Earth and how to avoid such a collision 2. The mission's primary objective, however, will be to collect an uncontaminated sample from Bennu's ancient surface, which is rich in organic molecules that can be used to study the deepest, murkiest past of the solar system 3.



1 Too Close for Comfort

In the year 2135, Bennu will come closer to Earth than the moon, missing our planet by some 300,000 kilometers. During that close encounter, the asteroid could pass through one of several kilometer-sized regions of space surrounding our planet called keyholes, in which Earth's gravity would tweak Bennu's trajectory to guarantee a collision during a future close encounter. If it strikes Earth, Bennu could release roughly as much energy as the detonation of all the warheads in the U.S.'s active nuclear arsenal.



3 The Journey of OSIRIS-REx

OSIRIS-REx's observations of the Yarkovsky effect will naturally emerge over the course of its mission, as it measures Bennu's shape, density and surface composition in search of a site for sample collection. After launching in September, the spacecraft will cruise for two years to Bennu, flying by Earth once to pick up additional speed. After arriving at Bennu in 2018, OSIRIS-REx will begin mapping the asteroid to pinpoint possible sampling sites. The spacecraft could visit one of the sites as early as July 2020, retrieving a sample via a retractable arm during a five-second "touch and go" maneuver. After a 2.5-year return journey to Earth, OSIRIS-REx will eject the sample capsule, which will reenter Earth's atmosphere and drift down to the Utah desert for collection.

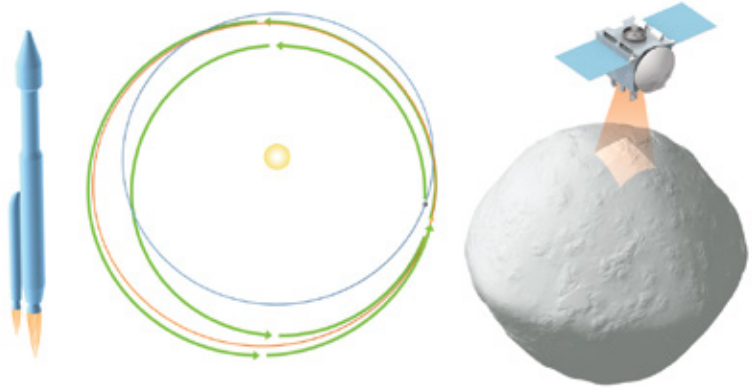
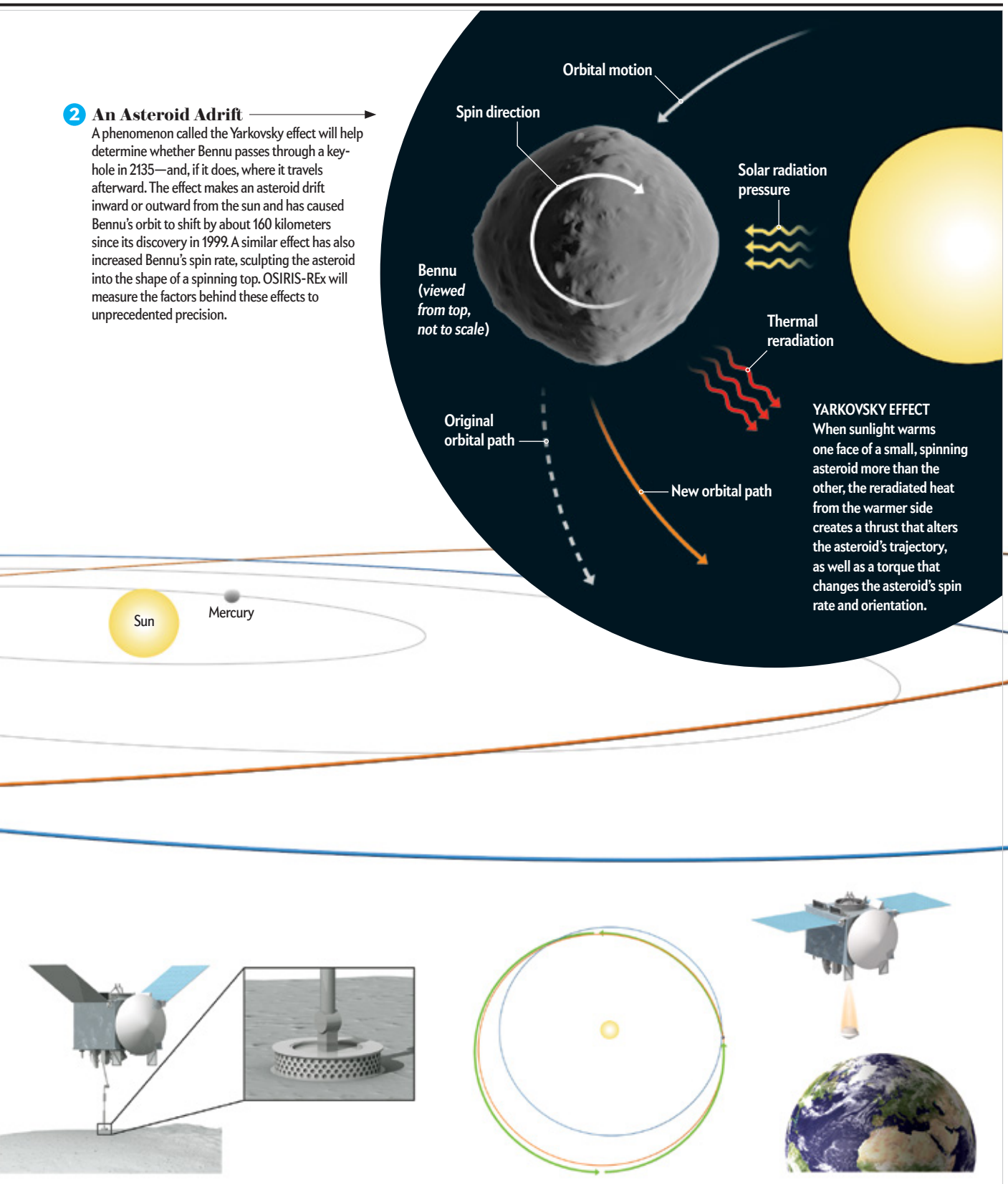


Illustration by Bryan Christie

2 An Asteroid Adrift

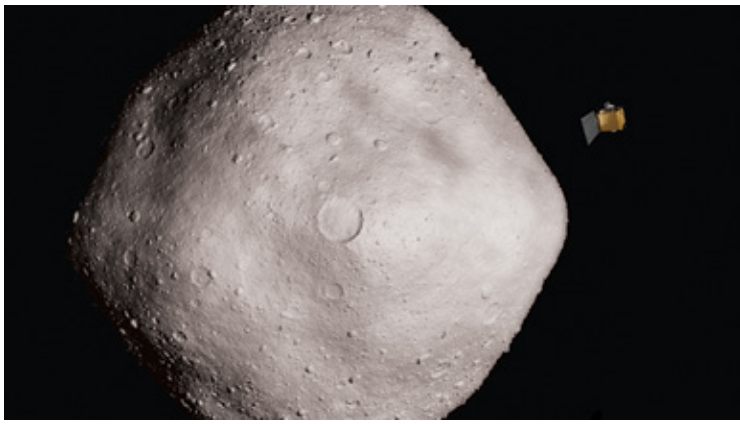
A phenomenon called the Yarkovsky effect will help determine whether Bennu passes through a keyhole in 2135—and, if it does, where it travels afterward. The effect makes an asteroid drift inward or outward from the sun and has caused Bennu's orbit to shift by about 160 kilometers since its discovery in 1999. A similar effect has also increased Bennu's spin rate, sculpting the asteroid into the shape of a spinning top. OSIRIS-REx will measure the factors behind these effects to unprecedented precision.



The samples returned by OSIRIS-REx will record a vast expanse of time, from before the solar system existed to the present day. Bennu's oldest minerals will be microscopic "presolar" grains that formed in the stellar winds emanating from dying stars. Eventually these grains were incorporated into the sun and its planets. Bennu's youngest constituents will be minerals and compounds altered by micrometeorite impacts, cosmic rays and solar flares. OSIRIS-REx's studies of these "space-weathering" processes on a carbonaceous asteroid will be unprecedented.

Like other carbonaceous asteroids, however, the bulk of Bennu's material will be organic molecules and water-rich clay minerals—the same stuff thought to have served as the raw feedstock for DNA, RNA, proteins and other building blocks of life on Earth. Some of Bennu's water was once liquid, kept warm in the asteroid's heart by the radioactive decay of short-lived isotopes such as aluminum 26 and iron 60. Immense numbers of carbonaceous asteroids must have fallen on the early, prebiotic Earth. But whether those asteroids actually brewed life's recipe cannot be easily answered on our planet—there are no unaltered rocks here old enough to tell the tale.

OSIRIS-REx is not only a mission to discover our deep origins; it will also gather information that will be important for our future. Several companies and nations are seriously investigating asteroid mining as a solution to resource limitations both on Earth and outside of it, examining ways to extract precious metals for use back on our planet or to use water ice for in-space production of rocket fuel. With its ability to precisely map and maneuver around an asteroid, OSIRIS-REx will serve as a pathfinder for future asteroid-mining missions.



BENNU'S SIZE, primitive composition and potentially hazardous Earth-crossing orbit make it a compelling and accessible target for sample-return missions, of which OSIRIS-REx may be only the first.

BENNU'S THREAT

ALTHOUGH IT IS NOT the mission's sole purpose, the value of OSIRIS-REx for improving asteroid-impact forecasts and prevention methods cannot be overstated. Determining whether an asteroid will hit Earth requires measuring the object's orbit to extreme precision. To appreciate the difficulty of that task, consider the distances and forces involved. Bennu circles the sun every 1.2 years, with an orbital velocity of more than 28 kilometers per second, and approaches Earth every six years. In a single orbit, this asteroid travels more than a billion kilometers; at its most distant, the asteroid is more than 340 million kilometers away from Earth.

Because it regularly comes relatively near to Earth, astronomers have been able to study Bennu's orbit closely enough to make it the most precisely recorded in asteroid catalogs. The uncertainty in its semimajor axis (the radius of its orbit at its two most separated points) is just six meters out of a total length of 168,505,699.049 kilometers. That is equivalent to measuring the distance from New York City to Los Angeles with an accuracy of about a third of a millimeter. But orbital accuracy alone is not enough, because many external forces can cause an asteroid's orbit to change.

To plot a course for Bennu, the OSIRIS-REx team uses high-fidelity models to compute the influence of all forces on the asteroid's orbit. These models must account for the gravitational effects of the sun, the moon, and the eight planets, as well as other large asteroids and the dwarf world Pluto. Even Earth's oblateness plays a role because it induces significant variations in a closely passing asteroid's trajectory. The models predict that Bennu will pass within 300,000 kilometers of Earth in 2135. What happens after that is harder to predict. This much is certain, however: if Bennu passes through one of several "keyhole" regions around Earth during its 2135 flyby, the accumulated gravitational effects will place it on track to strike the planet near the end of the 22nd century.

We simply do not know enough about Bennu to predict whether it will indeed pass through one of those keyholes. We currently calculate an approximately one in 10,000 chance of impact in 2196; tabulating all potential Earth impacts yields an estimated impact chance of roughly one in 2,700 sometime between 2175 and 2196. Yet Bennu appears just as likely to be ejected from the inner solar system entirely as it is to strike Earth. If it avoids these outcomes, it has an almost even chance of eventually falling into the sun and slightly less favorable odds of hitting Venus. Alternatively—although this scenario is much less likely—it could strike Mercury, Mars or Jupiter. Better models of Bennu's interior, surface and orbital interactions—models that OSIRIS-REx can provide—will allow us to increase the accuracy of our forecasts.

But OSIRIS-REx's greatest contribution to asteroid forecasting will be its investigations of a recently discovered nongravitational phenomenon called the Yarkovsky effect [*see box on preceding pages*]. The Yarkovsky effect describes the force that acts on a small asteroid when it absorbs sunlight and radiates the energy back into space as heat. When not evenly distributed across the entire asteroid, this thermal radiation acts like a minuscule thruster, causing the asteroid to drift and change its orbit over time. Asteroids with prograde rotations (spinning from west to east, like Earth does) drift away from the sun under this thrust. Asteroids with retrograde rotations, like Bennu, drift inward instead.

Already we have used ground- and space-based telescopes to measure the Yarkovsky effect on Bennu, revealing that its position has shifted more than 160 kilometers since its discovery in 1999. These measurements reveal that Bennu probably originated farther out in the asteroid belt, somewhere between Mars

COURTESY OF NASA GODDARD SPACE FLIGHT CENTER

SCIENTIFIC AMERICAN ONLINE Learn more about OSIRIS-REx's mission at ScientificAmerican.com/aug2016/osiris

and Jupiter, before migrating inward to its present position. Uneven solar illumination and thermal reradiation can also influence an asteroid's spin, which handily explains Bennu's spinning-top shape. The shape comes from sunlight falling asymmetrically on Bennu's surface, boosting its rotation rate over long periods and steadily driving surface material from its poles to its equator. The resulting wide-scale resurfacing may have brought fresh, unweathered material to Bennu's surface—ideal for obtaining a pristine sample.

OSIRIS-REx will perform a detailed study of the Yarkovsky effect by measuring Bennu's spin, surface area and thermal emission. We will also directly measure the Yarkovsky acceleration over the course of our encounter. This study will improve our theory of the Yarkovsky effect and allow us to incorporate it into impact-hazard assessments for all near-Earth asteroids. Additionally, better understanding the Yarkovsky effect could prove vital for future asteroid-deflection missions, which might exploit the effect to help nudge a hazardous space rock onto a different, less threatening trajectory.

THE GRAND FINALE

FROM BEGINNING TO END—from its origins in the mid-2000s to its conclusion in the 2020s and onward into its multigenerational legacy—OSIRIS-REx will represent decades of work and hundreds of millions of dollars of investment. All of that effort and expense will culminate in an act that lasts a mere five seconds: the touch-and-go maneuver, which the spacecraft must perform to gather a sample from the asteroid's surface.

At Bennu, decades of effort will culminate in an act that lasts a mere five seconds: the touch-and-go maneuver to collect a surface sample.

OSIRIS-REx will gather its sample using an instrument called the Touch-and-Go Sample Acquisition Mechanism, or TAGSAM. TAGSAM consists of two major components, a sampler head and an articulated positioning arm. The head acquires the bulk sample by releasing a jet of nitrogen gas that "fluidizes" the regolith and propels it into a collection chamber. The articulated arm positions the head for collection, brings it back for visual documentation and places it in a capsule for the return to Earth. As a backup, 24 separate surface contact pads on the TAGSAM base plate will acquire fine-grained material on touching the asteroid surface.

Most of OSIRIS-REx's three-year stay at Bennu will be spent preparing for this final maneuver. With its cameras, lasers, radio antennas and spectrometers, the probe will create multiple high-resolution global surveys of the asteroid. From these surveys, we will construct a "treasure map," which will identify a primary and a backup sample-collection site based on safety, the estimated ease of obtaining samples and the expected scientific value of any sampled material. The safest regions to visit will likely be near the equator, where the spacecraft can more easily match the velocity of the spinning asteroid to touch down on the surface. The most scientifically valuable sites should contain a diversity of organic compounds, water-rich minerals and other materials that could help us learn whether asteroids contributed to the origin of life on Earth.

Once the OSIRIS-REx team has chosen the primary sample-collection site and performed extensive dress rehearsals, the actual touch-and-go maneuver will begin. At this time, Bennu will probably be at the far end of its orbit, more than 18 light-minutes away from Earth. After we send the command to initiate the maneuver, we can only sit back and wait as the automated process unfolds. In a series of three propulsive burns over a period of hours, OSIRIS-REx will deorbit, align with its sampling site and then slowly descend toward the asteroid's surface. It will touch down at a maximum velocity of 10 centimeters per second. TAGSAM will have five seconds to collect samples before the craft blasts off from Bennu and rises to an altitude of roughly 10 kilometers above the asteroid. There it will perform a series of tests to ensure the sampling was a success. TAGSAM contains enough nitrogen for three sampling attempts—three strikes, and we will be out.

If all goes well, in 2021 the spacecraft will fire its main engines to return its precious sample to Earth. In late 2023, just after jettisoning the sample-return capsule into Earth's atmosphere, OSIRIS-REx will fire its engines again to enter a safe, stable graveyard orbit around the sun. The sample-return capsule will hit the top of the atmosphere at a speed in excess of 45,000 kilometers per hour, protected by a heat shield that will bleed off more than 99 percent of its reentry energy. At an altitude of three kilometers, the capsule will deploy a parachute, slowing to a soft landing in Utah's West Desert, seven years after its journey began. A team of specialists will recover the sample and transport it to the NASA Johnson Space Center for long-term storage and distribution so that the global scientific community can study it for generations to come. SA

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scientificamerican.com/magazine/sa

Scientists have figured out how venom injected by a tiny wasp turns a cockroach into its puppet—and into the perfect live meal for its offspring

By Christie Wilcox

BIOLOGY

ZOMBIE NEUROSCIENCE

I DON'T KNOW IF COCKROACHES DREAM, BUT I IMAGINE THAT IF THEY DO, JEWEL WASPS FEATURE prominently in their nightmares. These small, solitary tropical wasps are of little concern to us humans; after all, they don't manipulate our minds so that they can serve us up as willing, living meals to their newborns, as they do to unsuspecting cockroaches. It's the stuff of horror movies, quite literally; the jewel wasp and similar species inspired the chest-bursting horrors in the *Alien* franchise. The story is simple, if grotesque: the female wasp controls the minds of the cockroaches she feeds to her offspring, taking away their sense of fear or will to escape their fate. But unlike what we see on the big screen, it's not some incurable virus that turns a once healthy cockroach into a mindless zombie—it's venom. Not just any venom, either: a specific venom that acts like a drug, targeting the cockroach's brain.

Adapted from Venomous: How Earth's Deadliest Creatures Mastered Biochemistry, *by Christie Wilcox, by arrangement with Scientific American/Farrar, Straus and Giroux, LLC (US), Bungeishunju Ltd. (Japan).*

Brains, at their core, are just neurons, whether we're talking human brains or insect brains. There are potentially millions of venom compounds that can turn neurons on or off. So it should come as no surprise that some venoms target the carefully protected *central* nervous system, including our brains. Some leap their way over physiological hurdles, from remote injection locations around the body and past the blood-brain barrier, to enter their victims' minds. Others are directly injected into the brain, as in the case of the jewel wasp and its zombie cockroach host.

MAKING OF A ZOMBIE

JEWEL WASPS are a beautiful if terrifying example of how neurotoxic venoms can do much more than paralyze. The wasp, which is often just a fraction of the size of her victim, begins her attack

JEWEL WASP is a dazzling specimen—visually and evolutionarily. Its specially tailored venom has the power to hijack the brains of other insects.

ANAND VARMA *National Geographic*

from above, swooping down and grabbing the roach with her mouth as she aims her "stinger"—a modified egg-laying body part called an ovipositor—at the middle of the body, the thorax, in between the first pair of legs. The quick jab takes only a few seconds, and venom compounds work fast, paralyzing the cockroach temporarily so the wasp can aim her next sting with more accuracy. With her long stinger, she targets her mind-altering venom into two areas of the ganglia, the insect equivalent of a brain.

The wasp's stinger is so well tuned to its victim that it can sense where it is inside the cockroach's dome to inject venom directly into subsections of its brain. The stinger is capable of feeling around in the roach's head, relying on mechanical and chemical cues to find its way past the ganglionic sheath (the insect's version of a blood-brain barrier) and inject venom exactly where it needs to go. The two areas of the roach brain that she targets are very important to her; scientists have artificially clipped them from cockroaches to see how the wasp reacts, and when they are removed, the wasp tries to find them, taking a long time with her stinger embedded in search of the missing brain regions.

Then the mind control begins. First the victim grooms itself, of all things; as soon as the roach's front legs recover from the transient paralysis induced by the sting to the body, it begins a fastidious grooming routine that takes about half an hour. Scientists have shown that this behavior is specific to the venom, as piercing the head, generally stressing the cockroach, or contact with the wasp without stinging activity did not elicit the same hygienic urge. This sudden need for cleanliness can also be induced by a flood of dopamine in the cockroach's brain, so we think that the dopaminelike compound in the venom may be the cause of this germophobic behavior. Whether the grooming itself is a beneficial feature of the venom or a side effect is debated. Some believe that the behavior ensures a clean, fungus- and microbe-free meal for the vulnerable baby wasp; others think it may merely distract the cockroach for some time as the wasp prepares the cockroach's tomb.

Dopamine is one of those intriguing chemicals found in the brains of a broad spectrum of animal life, from insects all the way to humans, and its effects are vital in all these species. In *our* heads, it's a part of a mental "reward system"; floods of dopamine are triggered by pleasurable things. Because it makes us feel good, dopamine can be wonderful, but it is also linked to addictive behaviors and the "highs" we feel from illicit substances like cocaine. It's impossible for us to know if a cockroach also feels a rush of insect euphoria when its brain floods with dopamine—but I prefer to think it does. (It just seems too gruesome for the animal to receive no joy from the terrible end it is about to meet.)

While the cockroach cleans, the wasp leaves her victim in search of a suitable location. She needs a dark burrow where she can leave her child and the zombie-roach offering, and it takes a little time to find and prepare the right place. When she returns about 30 minutes later, the venom's effects have taken over—the cockroach has lost all will to flee. In principle, this state is temporary: if you separate an envenomated roach from its would-be assassin before the larva can hatch and feed and pupate, the zombification wears off within a week. Unfortunately for the envenomated cockroach, that's simply too long. Before its brain has a chance to return to normal, the young wasp has already had its fill and killed its host.

The motor abilities of the roach remain intact, but the insect simply doesn't seem inclined to use them. So the venom doesn't numb the animal's senses—it alters how its brain responds to them. Scientists have even shown that the stimuli that normally elicit evasive action, such as touching the roach's wings or legs, still send signals to the animal's brain; they just don't evoke a behavioral response. That's because the venom mutes certain neurons so they are less active and responsive, leading to the roach's sudden lack of fear and willingness to be buried and eaten alive. This venom activity requires toxins that target GABA-gated chloride channels.

GABA, or γ-aminobutyric acid, is one of the most important neurotransmitters in insect—and human—brains. If neuron activity is a party, then GABA is a wet blanket; it dampens a neuron's ability to be triggered through activation of chloride channels. When chloride channels open, they allow negative chloride ions to flow. Because these ions like to hang out with positive ions, if these channels are open when a sodium channel happens to open, chloride ions can cross the membrane at almost the same pace as sodium ions, making it harder for the sodium ions to start the domino cascade that is neuron signaling. Even though a neuron receives the "go" command, the action potential is stopped in its tracks. GABA isn't a complete inhibitor, however—the chloride channels can't wholly keep up with the sodium channels, so a strong stimulus can overcome the dampening effect. This dulling system is what the wasp co-opts to make the cockroach do her bidding. Her venom is packed with GABA and two other compounds that also activate the same chloride receptors, β-alanine and taurine. These also work to prevent the reuptake of GABA by neurons, prolonging the effect.

Christie Wilcox is a postdoctoral researcher in cellular and molecular biology at the University of Hawaii, where she studies venom. She is also a science blogger and communicator.

IN BRIEF

The jewel wasp depends on live cockroaches to provide crucial food for its newly hatched larvae.
To force cockroaches into submission and into a necessary torpor, the wasp has evolved a particular chemical mix that it injects into a roach's brain to alter its behavior and metabolism.
Many other wasp species also use complex venoms to parasitize spiders, caterpillars and even wasp larvae—sometimes turning them into zombie larva defenders.

SCIENTIFIC AMERICAN ONLINE Watch a video of a jewel wasp taking control of a roach at ScientificAmerican.com/aug2016/venom

HAVING GROWN—and nourished itself—inside its cockroach host, a wasp offspring emerges to start the macabre life cycle anew.

Although these venom compounds can cut the brain activity that would make her prey flee, what they can't do is make their way to the right parts of the cockroach brain by themselves. That's why the wasp has to inject them directly into the cockroach's ganglia. Fortunately for her, in a convenient quirk of nature, the same venom that zombifies roach brains works like magic to produce the transient paralysis needed to line up the cranial injection. GABA, β-alanine and taurine also temporarily shut down motor neurons, so the wasp only needs one venom to complete two very different tasks.

With her prey calm and quiescent, the wasp can replenish her energy by breaking the roach's antennae and drinking some sweet, nutritious insect blood. Then she leads her victim to its final resting place, using what remains of an antenna as an equestrian uses the reins on a bridle. Once inside her burrow, she attaches one egg to the cockroach's leg, then seals her offspring and the roach in.

FRESH MEALS

AS IF THE MIND MANIPULATION wasn't bad enough, the wasp's venom has one final trick. While the roach awaits its inevitable doom, the venom slows down the roach's metabolism to ensure it lives long enough to be devoured still fresh. One way metabolism can be measured is by how much oxygen is used up over time, as all animals (including us) use oxygen in the process of creating energy from food or fat stores. Scientists have found that oxygen consumption by cockroaches that have been stung is much lower than that of their healthy roach friends. They thought this might be the result of the reduced movement of the complacent victims, but even when paralysis is induced by using drugs or severing neurons, the stung cockroaches live longer. The key to the prolonged survival seems to be hydration. How exactly the venom acts to keep a roach hydrated is not known, but it ensures that when the wasp larva hatches from its egg, its meal is ready to eat. And soon enough after that, a new wasp emerges from the burrow, leaving the roach carcass behind.

ALAMY

Jewel wasp venom is only one example of neurotoxic venom taken to the extreme. There are more than 130 species in the same wasp genus, including the newly described *Ampulex dementor* (named for the soul-sucking guards of the magical prison Azkaban in the *Harry Potter* series). *Ampulex* belongs to a very large and diverse group of wasps, numbering at least in the hundreds of thousands of species, which are known for some serious mental manipulation. All have a macabre life cycle: as adults, they feed like other wasps and bees, but as larvae, they must feed off other animals. They're not quite independent, not quite parasites—they're parasite-ish, or as scientists call them, parasitoids.

Cockroaches are not their only targets; there are parasitoid wasps that lay their eggs in spiders, caterpillars and ants. The temperate Northern Hemisphere wasp *Agriotypus* will dive underwater to attach her eggs to caddis fly larvae and can remain submerged for up to 15 minutes to accomplish her task. The brave *Lasiochalcidia* wasps of Europe and Africa throw themselves into the nightmarish jaws of an ant lion, pry them apart and insert their eggs into its throat. There are even wasps called hyperparasitoids that parasitize other wasps like themselves, such as *Lysibia* species of Europe and Asia, which will sniff out caterpillars parasitized by fellow parasitoid wasps in the genus *Cotesia* and lay eggs in the freshly pupated wasp larvae. In some cases, multiple wasp species parasitize one another, leading to a Russian doll of parasitic interactions.

And to ensure their safe passage from larva to adulthood, these wasps often gain more than just a meal from their hosts. One of them turns its caterpillar hosts into undead bodyguards that will defend pupating young wasps that just ate through its body. Another species' larva forces its spider host to spin it a deformed but durable web to protect its cocoon just before killing the arachnid.

Whereas the wasps in this unusual family may have perfected the art of mind control, there are other venomous species whose toxins alter mental states. There are even species whose neurotoxic compounds get through our own blood-brain barrier, a feat that no wasp venom can yet achieve. But unlike cockroaches, we *Homo sapiens* have a strange affinity for substances that mess with our minds. Although the roaches run from those that would twist their brains, some people are willing to pay upward of $500 for a dose of venom to have a similar experience. SA

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Women in Science: 50 Fearless Pioneers Who Changed the World

by Rachel Ignotofsky. Ten Speed Press, 2016 ($16.99)

When bigoted colleagues at the University of California, Los Angeles, tried to assign ophthalmologist Patricia Bath an office next to the lab animals, she demanded to be moved. She went on to become the first African-American woman to receive a medical patent. Edith Clarke grew up in the 1880s with a learning disability but used an inheritance to pay for college and later invented a new graphical calculator. In 1922 she became the first woman to be hired as an electrical engineer. And Sylvia Earle, a marine biologist and "aquanaut" who lived in a habitat underwater for weeks at a time to do research, broke a depth record for untethered diving in 1979. Author and illustrator Ignotofsky profiles these and 47 other groundbreaking female scientists in this winningly illustrated collection, which combines profiles of the women with quotes, facts and cartoons depicting their lives.

I Contain Multitudes: The Microbes within Us and a Grander View of Life

by Ed Yong. Ecco, 2016 ($27.99)

There are more bacteria in the human gut than there are stars in the Milky Way, science writer Yong tells us in this ode to the microbial zoos living inside the human body. Long thought to be irrelevant, or even harmful, scientists are now realizing that the myriad of microbes we host are in fact critical to many vital processes—they help us extract nutrients from food, protect us from disease and can even affect how our genes behave. "Microbes have always ruled the planet but for the first time in history, they are *fashionable*," Yong writes, noting that the number of scientific papers on the subject has lately risen exponentially. His book is a lively look into the new science of the microbiome, explaining not just what these tiny lifeforms do for us but how they have evolved to play a major role in the life cycle of nearly every animal species on the planet.

Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy

by Cathy O'Neil. Crown, 2016 ($26)

The rise of Big Data— the slew of statistics readily available about people's lives, jobs, money, health, and more—has brought about an increasing reliance on mathematical models to make sense of it all. Companies now use algorithms to decide who should be hired and fired; banks consult them about who should get loans, and governments rely on them to determine which neighborhoods to police. Some of these models are helpful, but many use sloppy statistics and biased assumptions; these wreak havoc on our society and particularly harm poor and vulnerable populations, argues O'Neil, a data scientist and mathematician. She soured on such algorithms after they helped to lead Wall Street to the financial crisis of 2008 and calls these programs "Weapons of Math Destruction." "This type of model," she writes, "is self-perpetuating, highly destructive—and very common."

The Simple Beauty of the Unexpected: A Natural Philosopher's Quest for Trout and the Meaning of Everything

by Marcelo Gleiser. ForeEdge, 2016 ($22.95)

An accomplished physicist, Gleiser is also a nascent fisher. Here he merges those two passions into a book that is part memoir, part travelogue, part introduction to physics and part meditation on the meaning of life. The book follows his journeys to science conferences in locations that also offer fly-fishing opportunities; he explains both the research being discussed and his efforts to practice fishing, drawing surprising and often illuminating parallels between the two. For example, both are solitary pursuits that require one to take a chance—to cast out for a fish, to pursue a breakthrough—even though the odds are low that any given attempt will pay off. "The thrill is in beating the odds," he writes, "occasionally landing a big fish or an idea that reveals something new about the world."

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His book *The Moral Arc* is out in paperback (Henry Holt, 2015). Follow him on Twitter @michaelshermer

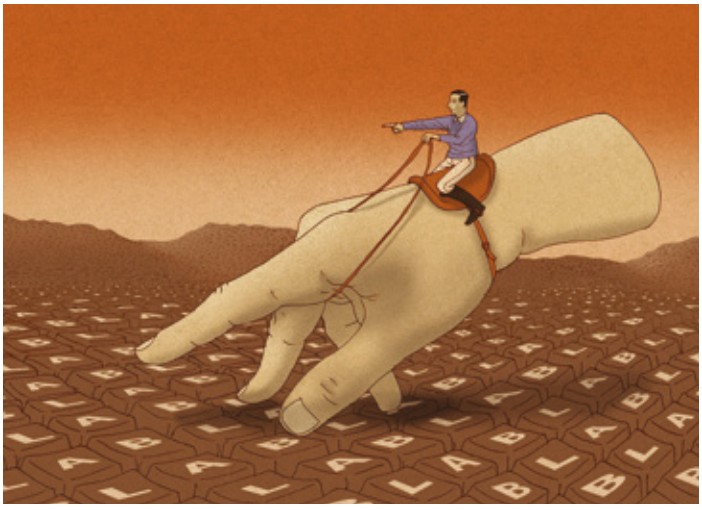
The Quack of the Gaps Problem

Facilitated communication, autism and patients' rights

By Michael Shermer

This past April 2, on World Autism Awareness Day, Apple released a heartstrings-tugging commercial depicting an autistic boy typing, in part with the assistance of a facilitator, a message on an iPad that voiced: "So many people can't understand that I have a mind. All they see is a person who is not in control. But now you can hear me. The iPad helps me to see not only my words, but to hold onto my thoughts."

The commercial was surprising because this system of "facilitated communication" (FC) was thoroughly discredited in the 1990s. Facilitators had used plastic alphabet keyboards or portable typing devices, and in various videos—for example, the 1993 *Frontline* episode "Prisoners of Silence"—you see children who are not even looking at the keyboard as facilitators direct their typing or facilitators moving the keyboard under a child's hand to produce the proper keystrokes. The technique was an academic curiosity until FC-generated messages included graphic descriptions of sexual abuse by families or caretakers of numerous children. Charges and lawsuits were filed, and courts needed scientists to determine who authored the accusations—the children or the facilitators?



Howard Shane, now director of the Autism Language Program at Boston Children's Hospital, and Doug Wheeler, then at the O. D. Heck Developmental Center in Schenectady, N.Y., conducted independent controlled experiments in which autistic children and their facilitators were shown pictures of either the same or different objects while blinded to what each other saw. What was typed was always and only what the facilitator saw.

Since then, as Emory University psychologist (and *Scientific American Mind* adviser) Scott O. Lilienfeld, an expert on pseudoscience in psychology and psychiatry, told Emory's eScienceCommons blog, dozens of controlled studies have unequivocally concluded that FC "doesn't work." Worse, "the false hope buoyed by discredited therapies can be cruel, and it may prevent people from trying an intervention that actually could deliver benefits." In a 2014 paper Lilienfeld co-wrote with Shane and others on "The Persistence of Fad Interventions in the Face of Negative Scientific Evidence" in *Evidence-Based Communication Assessment and Intervention,* a list of failed autism treatments included gluten-free diets, antifungal interventions, chelation therapy, nicotine patches, testosterone, marijuana, camel milk, weighted vests, magnetic shoe inserts and even bleach enemas.

Call it the Quack of the Gaps problem: gaps in scientific knowledge are filled with anyone's pet "theory" and corresponding "treatment." When the evidence is lacking, proponents accuse skeptics of being closed-minded or of using hate speech. At Syracuse University, where FC is still promoted through the Institute on Communication and Inclusion, 28 signatories issued a statement supporting FC in response to a series of critical articles in the university's newspaper, the *Daily Orange,* proclaiming FC "a fundamental right" and that these studies "are based on the foundation that people who type to communicate have been 'scientifically' labeled as intellectually lesser and thus what they type cannot possibly be attributed to them." So bias caused the negative results. "We must recognize that this argument has a history that spans groups of people in the U.S., a history of 'scientific' claims stating that … women are intellectually inferior, Blacks are intellectually inferior … these kinds of 'scientific' claims built upon intellectual inferiority are offensive and wrong."

What is offensive and wrong is promoting a pseudoscientific technique such as FC as "scientific" and responding to skeptics by accusing them of bigotry. As for rights, what about the rights of the nonverbal Australian man whose facilitator, Martina Susanne Schweiger, admitted in court in 2014 to sexually molesting him in 2011, when he was 21, because, she said, through FC he said he loved her? Or the rights of the then 30-year-old African-American man with severe mental disabilities whose facilitator, the Syracuse-trained Anna Stubblefield, was sentenced to 12 years in prison in 2016 for sexually assaulting him in 2011, after she determined through FC that they were in love? Or the rights of the many loving parents and caretakers wrongfully accused of sexual abuse purely through FC?

Yoking the rights of autistic children to FC is self-serving sophistry. People with autism have the same rights as everyone else *regardless of their communication skills.* Rights are not vouchsafed only to those who can communicate, and of all people, those working at universities should know that. Shame on them. SA

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Illustration by Izhar Cohen

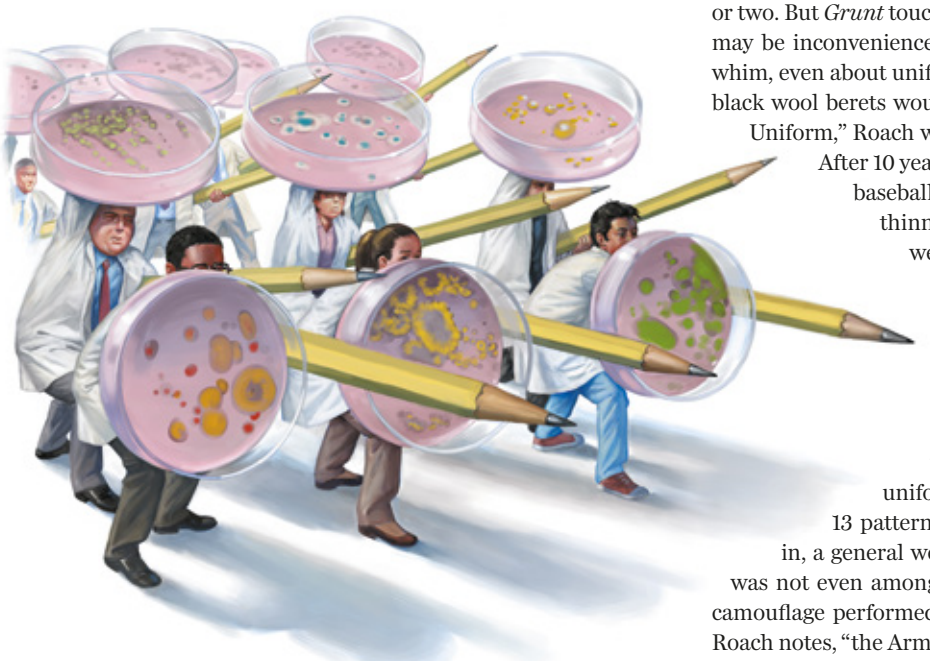
Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 35 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

The War by Science

Military science goes way beyond missile trajectories

By Steve Mirsky

When I was a kid, the taunt "Your mother wears Army boots" had not yet gone completely out of fashion. But the razz packed no punch for me. I could respond, "Actually she wears Marine Corps boots, and she will beat the hell out of your mother." She had indeed been in the Corps, where she met my father. They were both sergeants. In his later years, my dad was fond of issuing his own taunts to ex-officers of other branches of the military, things like "You were a colonel in the Army? That's like being a corporal in the Marines."



They have both received their honorable discharge from this life, but I know my folks would have appreciated some of the stories in Mary Roach's new book, *Grunt: The Curious Science of Humans at War*. Particularly the one involving another Marine Corps sergeant, name of Robinson, and Captain Mark Riddle, a Navy research physician. Riddle's specialty is diarrhea: "I live and breathe this stuff," he says in *Grunt*.

Roach, Riddle and Robinson discussed diarrhea over breakfast at Camp Lemonnier in Djibouti. (In Iraq and Afghanistan, 32 percent of respondents in a Riddle survey reported an incident of having been unable to reach a toilet in time.) Robinson complained about the minuscule amount of toilet paper included with combat field rations. Riddle noted that Navy personnel sometimes pack baby wipes. Robinson replied that Marines use pieces of their T-shirts. Roach writes, "Which possibly sums up the whole Marine Corps–Navy relationship."

In her book, Roach takes a deep dive into military science and medicine and how even the simplest activities are complicated by the realities of combat or readiness for it. For example, most of us may take for granted being able to hear co-workers when collaborating on a task. But ears take a constant beating in the service—weapons and explosions, Roach writes, "are the biggest contributors to the $1 billion a year the Veterans Administration spends on hearing loss and tinnitus."

A platoon's members might want to protect their ears with plugs or higher-tech devices but not at the expense of being able to hear commands and warnings. And so well-meaning audiologists do a lot of testing and try to come up with solutions for use in the field. But when a group of special-ops personnel was asked if an audiologist had ever done anything positive for them, the only reply, Roach says, was, "They fitted me for my hearing aids."

A general or admiral has undoubtedly made a good decision or two. But *Grunt* touches on how thousands of men and women may be inconvenienced or endangered by some mucky-muck's whim, even about uniforms. "An Army chief of staff decided that black wool berets would be the headpiece of the Army Combat Uniform," Roach writes, because he thought it looked sharp. After 10 years, the Army was finally able to get back to baseball caps, with their eye-shading visors and thinner fabric, which makes them cooler to wear and easier to jam into a pants pocket—attributes that are actually functional.

In the early 2000s the Army attempted to come up with a Unified Field Theory, not for physics but for camouflage uniforms: they wanted one pattern that would hide troops in the woods, city streets and the desert. The uniform designers and engineers came up with 13 patterns for testing. But before the results were in, a general went ahead and picked a pattern—one that was not even among the 13 agreed-on contenders. "The new camouflage performed so poorly in Afghanistan that in 2009," Roach notes, "the Army spent $3.4 million developing a new and safer pattern for troops deployed there."

Meanwhile the Navy currently wears blue camouflage as its working uniform. "I asked a Navy commander about the rationale," Roach recounts. "He looked down at his trousers and sighed. 'That's so no one can see you if you fall overboard.'"

Maybe some high-ranking officers should have followed their hearts and become fashion designers. The grunts would be happier, the officers would be happier and they might have come up with a thicker-ply T-shirt for the Marines. SA

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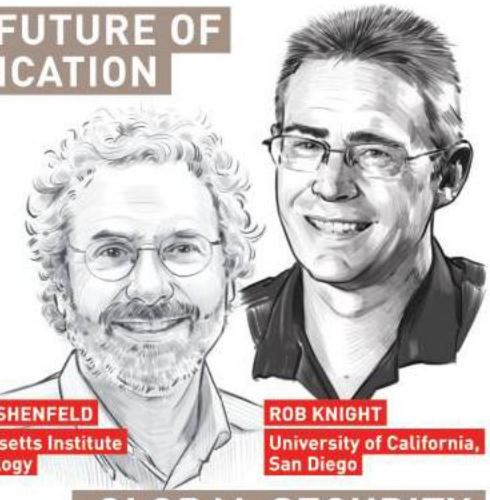

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1966 In Vitro

"If rabbit and pig eggs can be fertilized after maturation in culture, presumably human eggs grown in culture could also be fertilized, although obviously it would not be permissible to implant them in a human recipient. So far we have either failed or have at best achieved a very limited success in fertilizing human eggs in vitro. We intend to continue these experiments; the ability to observe cleaving human eggs could be of great medical and scientific value. For example, sterility caused by faulty passage of embryos along the fallopian tube could probably be alleviated by removing oocytes from the ovary, growing and fertilizing them in vitro and then transferring them back into the mother.—R. G. Edwards"

Robert G. Edwards won a Nobel Prize in 2010 for this work.

1916 Powering Progress

"For the great electrification plans of the Puget Sound lines of the St. Paul Railway, a great system of power houses will supply the current necessary for the operation of these lines. The illustration shows one of the great turbine water wheels that will be used for generating the electricity at one of the principal stations of the Montana Power Company. The transmission lines of the company form a network that covers the greater part of Montana and a portion of Idaho, supplying electric power not only for 440 miles of railway, but also furnishing power for many mining enterprises. For this work the power company has twelve power stations, which will have an ultimate capacity of 243,890 kilowatts."

For archive images showing the supply and use of electricity in 1916, visit www.ScientificAmerican.com/aug2016/electricity

1966

1916

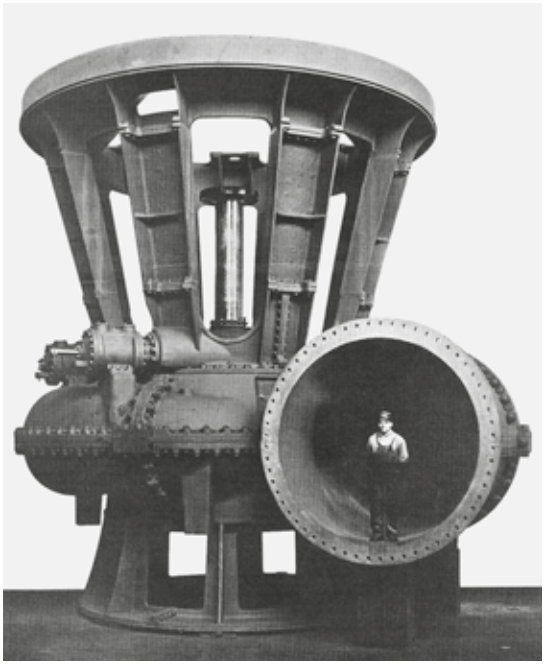
1866

Innovations in Warfare

"The most radical development of the war has been the substitution of trench warfare—in which the rival armies are held fast and practically immobile in positions which have no flanks—for the free movement of armies in the open field. In the new trench warfare the most radical developments have been, first, the elimination of long-range rifle fire, and, secondly, the substitution of the modernized ancient hand grenade for the rifle. It is found that in the storming of positions the infantry are less hampered in their movements and do more effective work with the hand grenade than with the rifle."

1866 Pricey Telegraph

"We had occasion to send a telegraphic message to our correspondent in London, through the Atlantic Cable, consisting of exactly twenty words, which, according to the published schedule, should have gone forward for £20 sterling, but the director at this end charged £24, or $120 in gold, so as to cover the date of transmission. We wish the Submarine Telegraph Company success, but it seems to us impossible that the public can submit to such exorbitant, and as it appears to us, unreasonable charges."



1916: A 15,000-horsepower turbine for powering the electrically operated section of the Chicago, Milwaukee and St. Paul Railroad in Montana.

Urban Meat

"A new abattoir is now in the course of construction at the foot of East 106th Street, New York. It is intended to supersede the slaughter houses at present existing, which cause a great deal of sickness and mortality in hot weather among those who live in proximity to them. The building, constructed of wood, is built facing the river, upon piles driven into the ground below high-water mark, and has a platform on the river side with gutters and gratings to carry off all refuse to below low water mark. There are 20 hoisting apparatuses, thus enabling them to slaughter as many as 1,500 bullocks in one day. The blood will be used for fertilizing purposes, the fat melted and sold, and all other matter drained off."

Vice and Profit

"The *East Indian Budget,* just laid before the British Parliament by Lord Cranborne, presents some curious facts relating to the opium trade as a source of revenue. The gross revenue of the Government for the years 1864–5 amounted to £47,041,000, showing a small surplus beyond expenditures, owing to the unexpected receipts from the customs tax on opium. These amounts are paid wholly by the Chinese, by whom the drug is consumed. It is now believed that the demand of the Chinese for opium can be depended upon as safely as English chancellors of the exchequer can rely upon the demand for gin and beer."

SCIENTIFIC AMERICAN, SUPPLEMENT, VOL. LXXXII, NO. 2121, AUGUST 26, 1916

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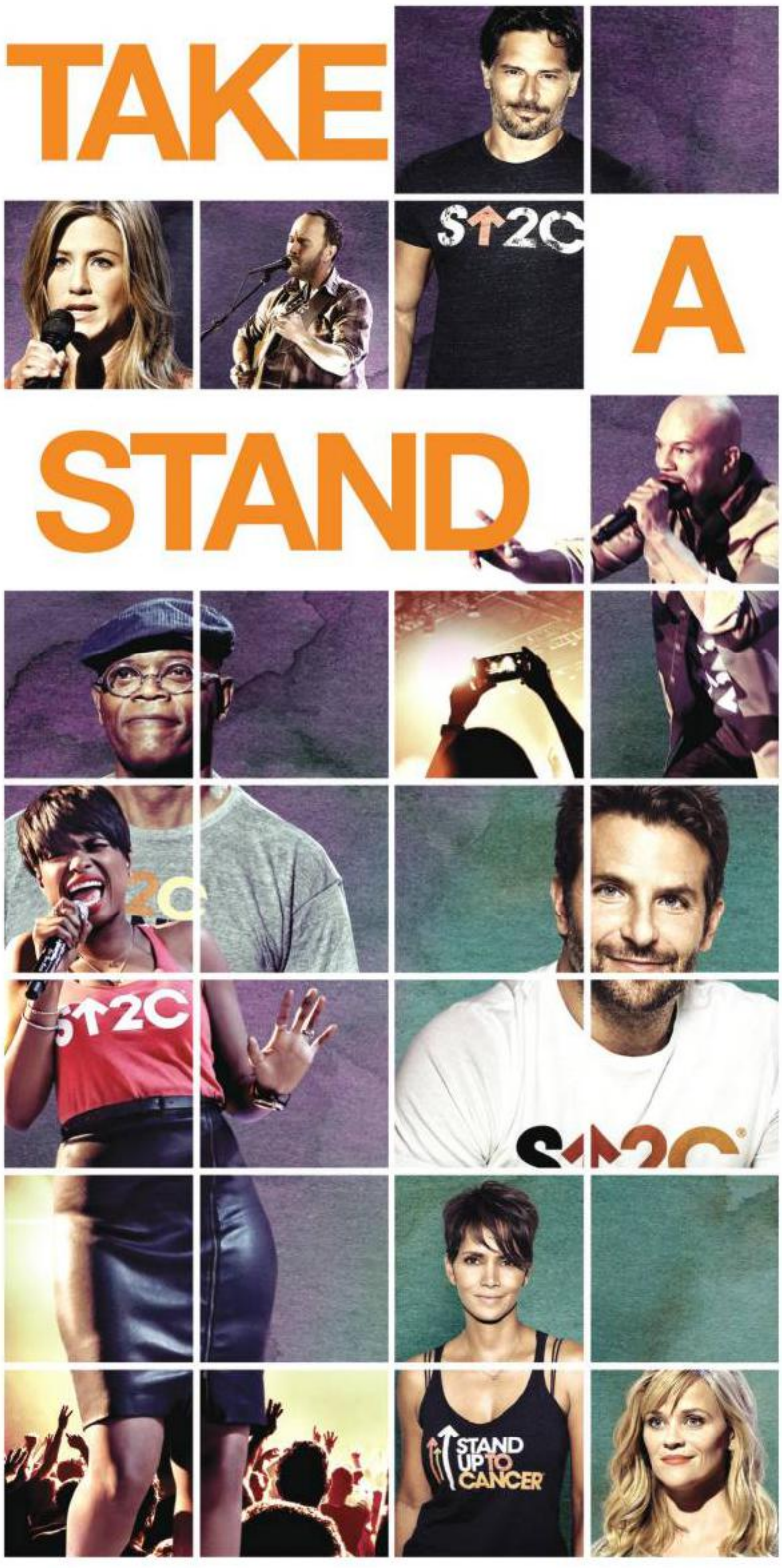

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Fatter Still

The world is entering a new era of severe obesity

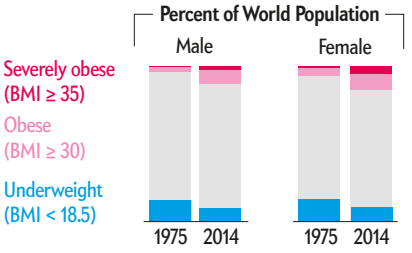
People in many developing nations, such as Liberia and Georgia, are gaining weight at a rapid pace, faster since 2000 than they did from 1975 to 2000 (*among pink icons*). And although the rate of weight gain in many developed countries since 2000 is slower than it was prior (*among orange icons*), it has kept going up. When taken together, the two trends mean that "for much of the world, we are passing from an era of obesity into a new era of severe obesity," says Majid Ezzati, lead scientist on a far-reaching study of 200 countries published recently in the *Lancet*. Researchers "are surprised by the extent of severe obesity," he says (*bar chart*). If the trajectory continues, Ezzati says, it will be virtually impossible to meet the World Health Organization's global goals of halting the rises in obesity and diabetes by 2025.

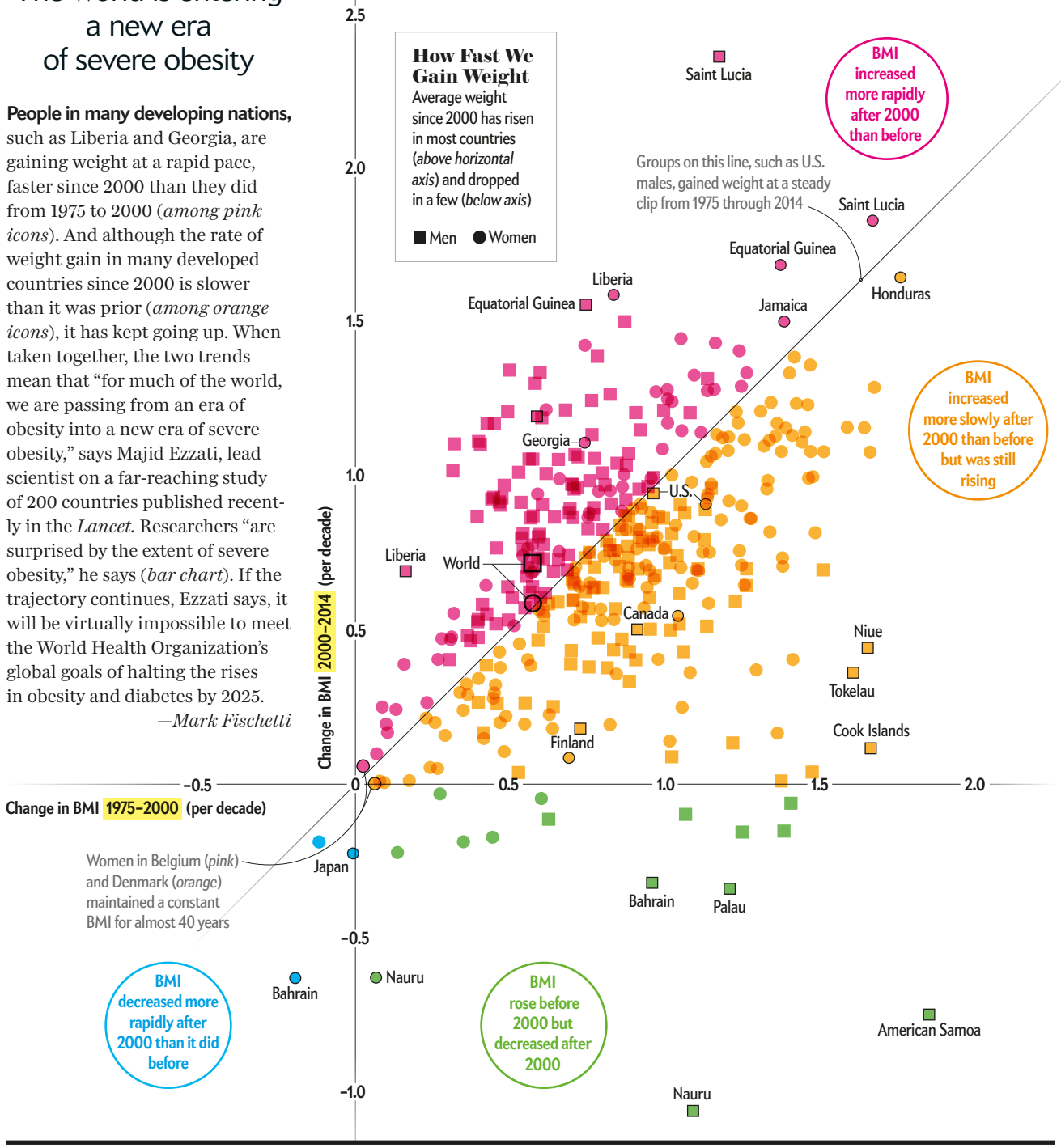
—Mark Fischetti

Humans Get Heavier

From 1975 to 2014 the proportions of men and women who were obese (*pink*) and severely obese (*red*) rose significantly. The good news is that the prevalence of underweight people lessened (*blue*), although many millions still suffered. A body mass index (BMI) of 18.5 to 25 is considered healthy. (Gray represents healthy or overweight.)

BMI = weight in kilograms/height in meters squared





SOURCE: "TRENDS IN ADULT BODY-MASS INDEX IN 200 COUNTRIES FROM 1975 TO 2014: A POOLED ANALYSIS OF 1698 POPULATION-BASED MEASUREMENT STUDIES WITH 19.2 MILLION PARTICIPANTS," BY NCD RISK FACTOR COLLABORATION; IN *LANCET*, VOL. 387; APRIL 2, 2016; NCD RISK FACTOR COLLABORATION *www.ncdrisc.org (data)*

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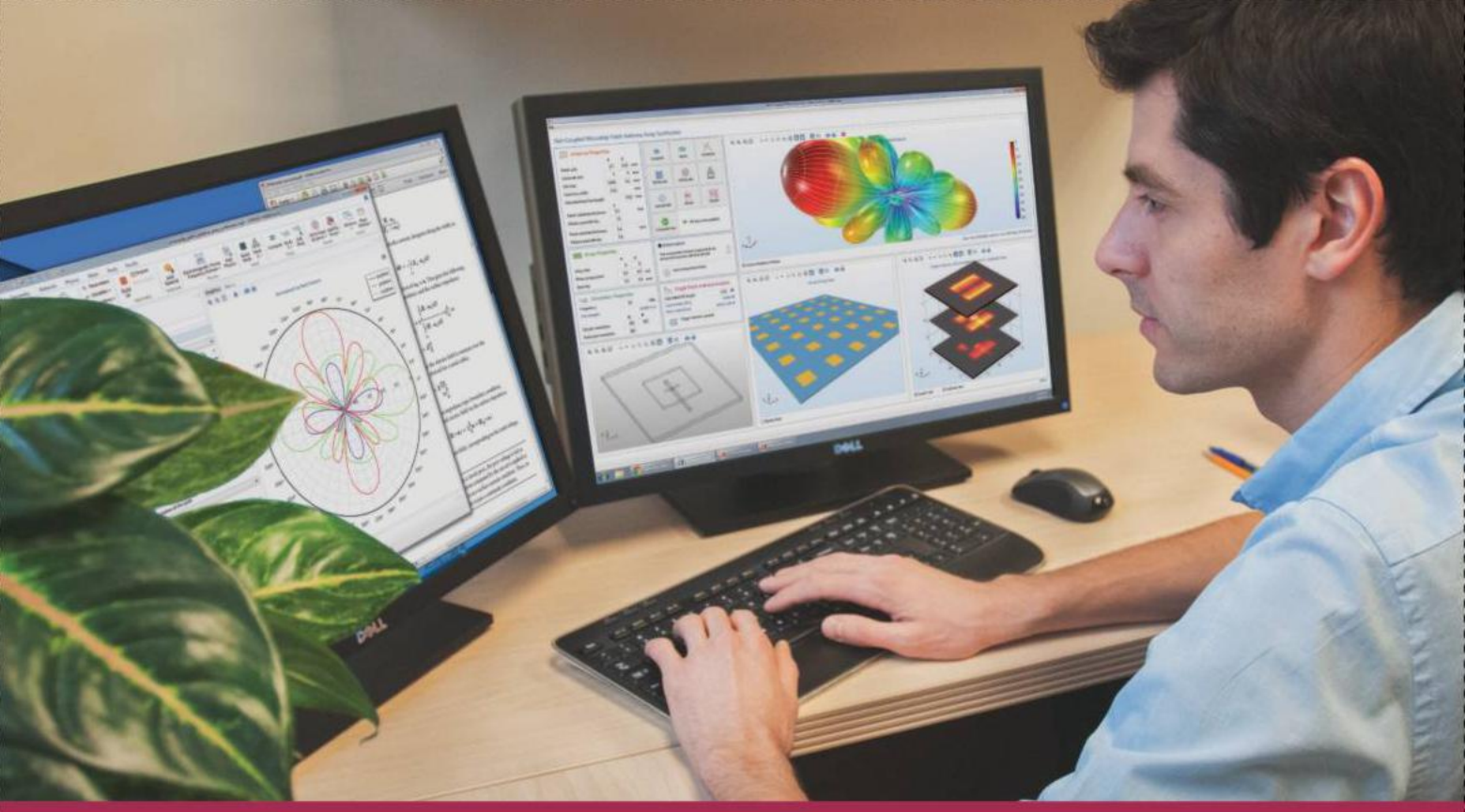

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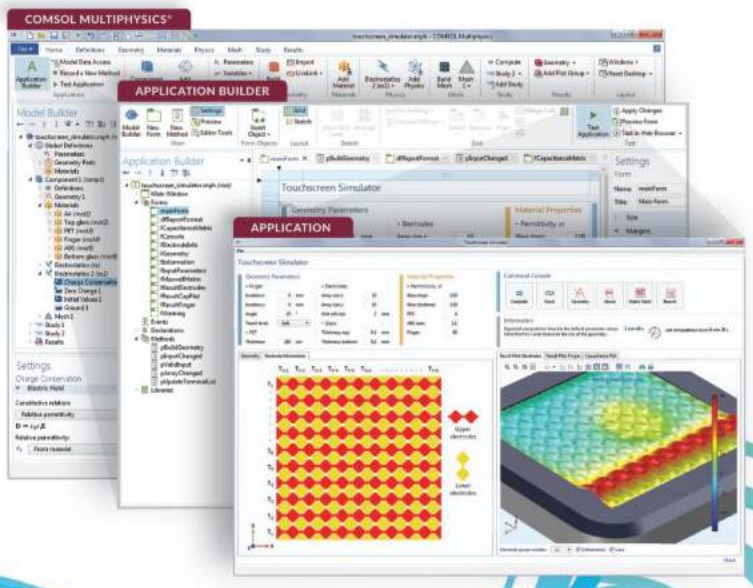

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