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GENE THERAPY TO HEAL HEARTS PAGE 38

SCIENTIFIC AMERICAN

LAB-MADE BRAINS

"Organoids" could help solve Alzheimer's, autism and more

PLUS

FROM DINOSAUR TO BIRD

An evolutionary tale PAGE 48

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Advances in veterinary forensic science PAGE 56

JANUARY 2017
ScientificAmerican.com

THE GALIEN FOUNDATION

www.galienfoundation.org

THE GALIEN FOUNDATION | MISSION

The Prix Galien is more than an award: it is a movement with a mandate to foster, recognize and reward excellence in scientific innovation to improve the state of human health. Building on an unrivaled network of Nobel Laureates in medicine, the Prix Galien manages an independent, cross-functional and geographically diverse program of events and sponsorships to brand "the best of the best" in new medicines and diagnostics.

Our scope is global, and our commitment to progress in medicine is both measurable and concrete. Our members express this through the establishment of productive relationships to build lasting bridges between the commercial research enterprise and local communities engaged in public policy, science, finance, academic research and the media.

In addition to recognizing advances in promising therapies, the Prix Galien's annual Pro Bono Humanum Award for humanitarian achievements brings a unique focus to the intersection between science, business and politics. The outcome we seek is guided by the synthesis principle that underpins the conduct of science itself: successful innovation where financing, physical assets, knowledge and skills are combined from many sources to move new ideas quickly **"from the bench to the bedside,"** on behalf of patients everywhere.

A truly global program present in 14 countries*

Our program includes a review of contributions from a new generation of innovators representing diverse sectors in health as well as from the emerging markets of the developing world. Our theme: better cross-cultural contacts, harmonized regulation, internal business process improvements, new information technologies and effective public-private partnerships can remove barriers to the commercialization of good medicines and expand access to these benefits to all who need them.

2016 will represent a new and exciting stage in the evolution of the Prix Galien as the pre-eminent **"force populaire"** behind the global scientific enterprise. With the support of our sponsoring organizations, our efforts will extend to all who see medical innovation not only as an industrial policy asset but as a source of social progress – where private enterprise and public engagement combine to deliver a greater public good.

We invite all communities with a commitment to the conduct and promotion of life sciences innovation to contribute to this important work.

* Belgium, Canada, France, Germany, Greece, Italy, Netherlands, Poland, Portugal, Russia, Spain, Switzerland, United Kingdom and the United States.

SAVE THE DATE
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The Prix Galien Award recognizes outstanding achievements in improving the global human condition through the development of innovative drugs and other treatments.

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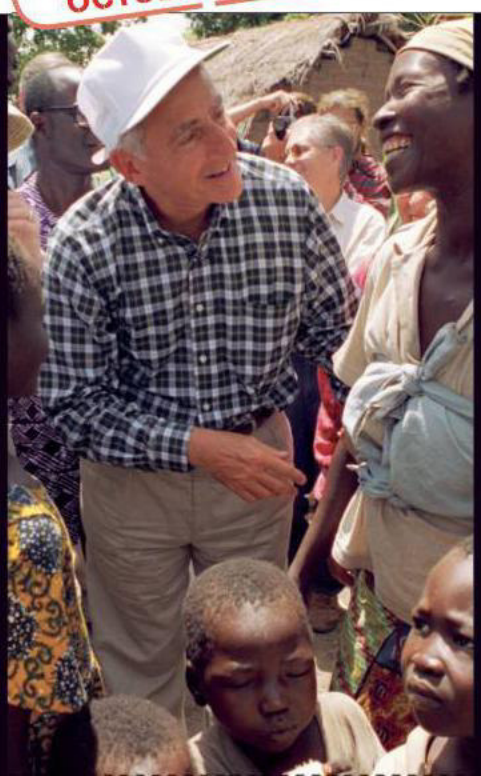

INNOVATION TO IMPROVE THE HUMAN CONDITION

Pr Roy VAGELOS during the campaign against river blindness in West Africa.

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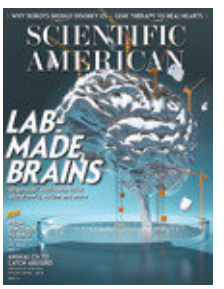

ON THE COVER

New tools allow neuroscientists to grow parts of a brain in a lab dish. These "organoids" model the human brain more realistically than mice or other animals do. Brains-in-a-dish have already been put to good use to understand the Zika virus. Image by Bryan Christie.

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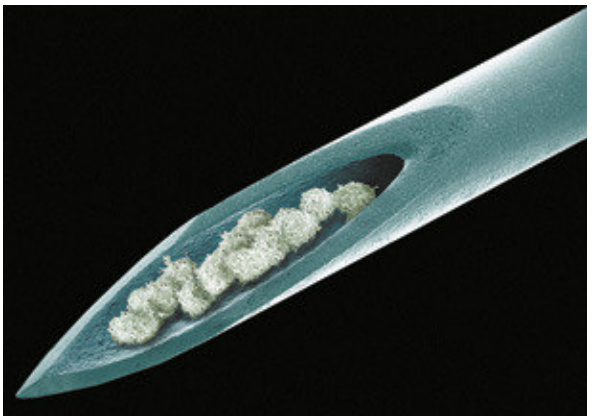

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ON THE WEB

Breakthrough Prize
Scientific American spotlights the 2017 winners' outstanding scientific achievements.
Go to www.ScientificAmerican.com/jan2017/breakthrough

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

What's Next for Science?

Wednesday, November 9, dawned gray and raw in Berlin. I was there to moderate a couple of panels at an annual meeting called Falling Walls. The name and timing celebrate the anniversary of the Berlin Wall's fall, as well as the free exchange of ideas if only we can knock down barriers. I looked forward to a series of inspiring talks about how science, which I have often called the "engine of human prosperity," could help us solve some of our greatest challenges.

We all crowded into a large room at the start of the day. A live broadcast began, looming above us on an enormous screen. The Falling Walls attendees watched the acceptance speech of the U.S. president-elect, Donald Trump, whose campaign included a promise to build a new wall.

What would this mean for science, I wondered? As a candidate, Trump had made some troubling antiscience statements, including tweeting that global climate change is a Chinese plot, threatening that he would dismantle the agency that enforces clean air and water regulations, and endorsing the long-disproved link between vaccines and autism. Any hope that he would soften those stances after victory were quickly dashed. His first actions as president-elect included putting forward a climate change skeptic to head the Environmental Protection Agency and reportedly looking to make good on his earlier intent to pull out of the Paris climate accord.

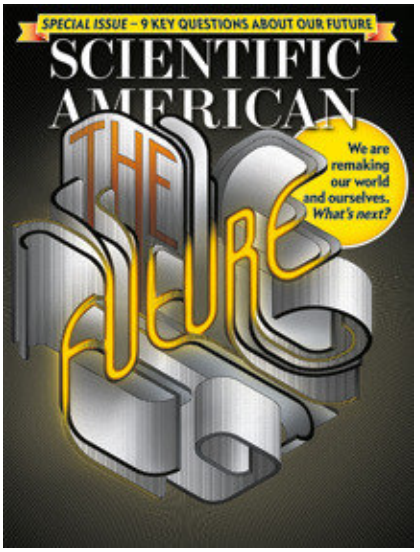
BERLIN WALL being destroyed in November 1989.

For 171 years, *Scientific American* has chronicled the advances of science (and even fostered its application, with its patenting offices, starting in 1850). While at Falling Walls, I reflected on how many voters had come to feel disenfranchised in the face of that progress, leaving them with a sense of reduced opportunity. I thought about how we who work in and around science could be more inclusive in our outreach to them and to policy leaders and how we could help take a systems approach to better ensure that research will be applied in ways that result in greater public benefit. I thought about how we could still work together to build a better world. We just might have to try a little harder to get there. For these reasons, we are expanding the scope of our reporting on public policies that will affect science to round out our traditional coverage of the impact of that research on human lives.

One thing is as clear today as it was when this magazine was founded in 1845, during the flowering of the industrial revolution in the U.S.: a world in search of solutions to humanity's challenges needs information about science, and *Scientific American* will be tireless in providing it. SA

JOHN GAPS III AP Photo

Illustration by Nick Higgins



September 2016

THE ANTHROPOCENE

In "A History in Layers," Jan Zalasiewicz argues that humans' effect on the earth calls for the establishment of a distinct geologic epoch called the Anthropocene.

If humans stay around on the earth for millions of years, naming the present era the Anthropocene will most likely be justified. On the other hand, there is a distinct possibility that we shall succeed in exterminating ourselves within a short period. In that case, the impact of humanity would rather resemble that of the asteroid that killed the dinosaurs. On the geologic timescale, it would be the blink of an eye—short and terrible. Then some other future species will handle the naming issue.

Soeren Hansen
Kongens Lyngby, Denmark

WHITHER NEUROSCIENTISTS?

Senior editor Gary Stix reports on the contrast between a growing number of neuroscience Ph.D.s and the progressively reduced number of positions in academic research and asks, "Where Will All the New Neuroscientists Go?" [Advances]. As a psychiatrist, I encourage such Ph.D.s to go to medical school and specialize in psychiatry. Individuals who suffer from mental illness, and those who treat them, are greatly in need of more neuroscientists to help delineate the biological underpinnings of mental disorders and their effective treatments. Because these underpinnings help create the complex human mind—and complete person—we should also reaffirm the critical skills psychiatrists need to understand and communicate effectively with that person. Psychiatry has never been more compelling, and it needs good people.

Jon D. Sobotka
Corvallis, Ore.

"Although increasing the years of healthy life reduces the costs of health care, healthy elderly still consume resources."

MARTIN J. GREENWOOD *STIRLING, AUSTRALIA*

SUSTAINABLE CENTENARIANS?

Bill Gifford does not discuss the economic burden that would be created by a substantial increase in healthy life span in "Living to 120." Many human activities are benign when only a few participate but become problematic when too many do it. Living longer is an affordable indulgence when becoming a centenarian is rare enough that it can be marked by a letter from the British monarch. What happens when 7.4 billion of us aspire to such an age? Although increasing the years of healthy life reduces the costs of health care, the healthy elderly still consume resources.

Martin J. Greenwood
Stirling, Australia

CONSCIOUSNESS AND PHYSICS

In "At the Boundary of Knowledge" [Skeptic], Michael Shermer argues that physics disproves, or reduces to the vanishing point, the possibility of paranormal phenomena. Instead of beating the dead horse of scientific atheism, he should have considered a far more amazing current trend that places so-called supernatural phenomena on the same playing field as natural events: in physics and biology, a crisis of knowledge has developed when attempting to account for the fundamental definitions of time, space, matter, energy and life. In a cosmos ruled by dark matter and energy, where no empirical evidence exists about the origin of time, the multiverse is pure conjecture and no one knows how the fundamental physical constants emerged from the big bang, Shermer's stubborn physicalism is not true to the current situation in science.

A growing cadre of investigators has opened the door to a once forbidden subject: consciousness. Until we understand how consciousness comes about, both normal and paranormal events are equally mysterious. Two observers—one claiming to see angels, the other to see nebulae and galaxies—derive their experience from totally unknown processes by which the brain, using ordinary electrochemical activity, produces a 3-D world. Max Planck declared, "All matter originates and exists only by virtue of a force…. We must assume behind this force the existence of a conscious and intelligent Mind. This Mind is the matrix of all matter." Werner Heisenberg asserted, "The atoms or the elementary particles themselves are not as real [as phenomena in daily life]; they form a world of potentialities or possibilities rather than one of things or facts."

It's time for Shermer to read these seminal physicists so that instead of relying on a primitive belief that all phenomena come down to the interaction of particles, he gets into the game when it's finally becoming interesting.

Deepak Chopra
University of California, San Diego, School of Medicine

SHERMER REPLIES: The door to the once forbidden subject of consciousness was opened by hard-core natural scientists such as Francis Crick and Christof Koch, who collaborated on models to explain how conscious experiences arise from neural activity without invoking the supernatural. And it is tautologous to assert that conscious experiences are explained by consciousness. How neural processes lead to conscious experiences is becoming understood through the tools of neuroscience, and while the hard problem of explaining consciousness is not yet solved, by no means is it the result of "totally unknown processes."

As for Planck and Heisenberg: two quotes do not an argument make. Most physicists do not assume a conscious, intelligent mind is behind matter and energy, and the nature of atoms and elemen-

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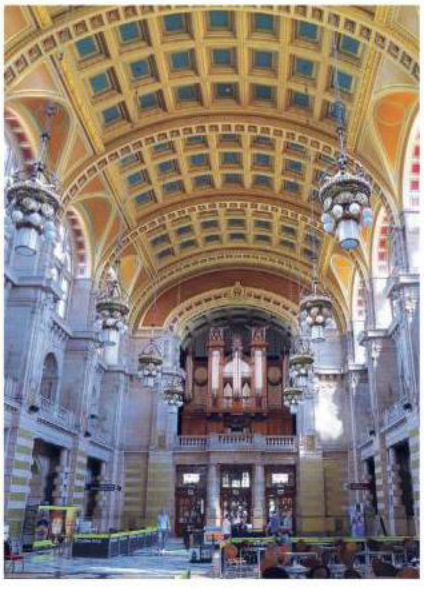

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tary particles may be a world of potentialities, but at the macro level, where we live, you need only to thrust your fist into a brick wall to refute Chopra's assertions.

DEAD TAPE

In "What to Do with All Those Cassettes" [TechnoFiles], David Pogue describes "the world's VCR and camcorder tapes" as now "rotting in boxes" and encourages readers to digitize them. Pogue shouldn't be so fast to imply that analog media are no longer used at all. I have stacks of videocassettes and audiocassettes—even eight-track tapes. I also have shelves of vinyl LPs, some of which are irreplaceable. And a few weeks ago I wandered into a bookstore (another rarity), and what do I see right inside the doors? A huge display of vinyl LPs and signs touting their advantages.

SANDOR FRECSKA
Mannington, W.V.

CLARIFICATIONS

"A History in Layers," by Jan Zalasiewicz, referred to the Holocene starting 11,700 years ago, with glaciers "melting so much they raised sea level globally by 120 meters." That 120-meter rise specifically occurred between 18,000 and 8,000 years ago, across the transition from the Pleistocene to the Holocene. Additionally, the box entitled "When Did the Anthropocene Begin?" should have specified that plutonium 239 decays into uranium 235 and not implied that plutonium 240 does.

ERRATA

"The Kilogram Makeover," by Knvul Sheikh [Advances], incorrectly stated that contraction or expansion of the Le Grand K cylinder can alter its mass. Instead molecules could escape from the cylinder in a process called outgassing, which would cause it to lose mass. It could also gain mass from molecules landing on and sticking to its surface. Further, it should have credited the National Institute of Standards and Technology as the source for the statistics in the "By the Numbers" box.

In "A Tale of Two Worlds," by Mara Hvistendahl, the box by Pamela Ronald entitled "Can We Feed the Planet without Destroying It?" incorrectly said Ronald is a professor emerita at the University of California, Davis. She is an active professor there.

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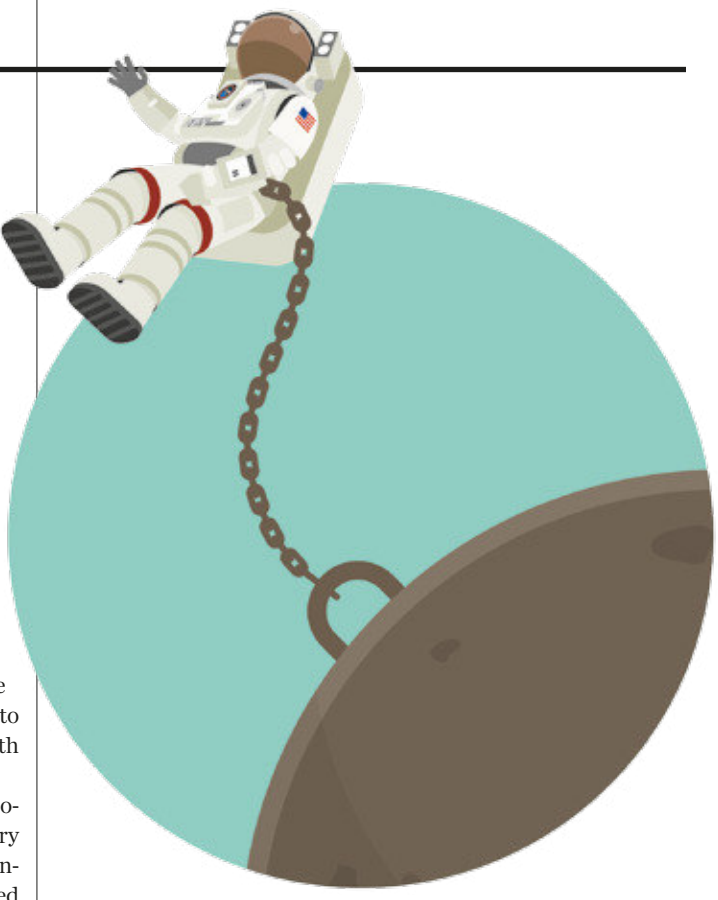
Let NASA Take Flight

Donald Trump and Congress should end Washington's bad habit of shifting our space goals

By the Editors



As a newly minted president, Barack Obama told NASA to steer away from the moon—a destination set by his predecessor George W. Bush—and head for Mars instead. Richard Nixon encouraged NASA to cancel its final Apollo missions to divert funds to the space shuttle program. Unfortunately, President-elect Donald Trump seems set to follow this precedent. "After taking office, we will have a comprehensive review of our plans for space and will work with Congress to set both priorities and mission," he told *SpaceNews* a month before the election.

These repeated relaunches come at great cost. Space exploration is a long-term proposition: changing our minds every four or eight years means wasting effort, time and money. Another reshuffle could prove disastrous. NASA has finally regained momentum after its last change of plans in 2010 and says it is on track with its giant Space Launch System (SLS) rocket, intended to target the Red Planet. "This is not a time that we can start over," NASA administrator Charles Bolden said in October 2015. Our space program needs stability, and several groups have proposed changes that could help.

One is that NASA administrators should serve terms longer than four years. Currently, when each president takes office, he or she can nominate a new administrator, to be confirmed by the Senate. The nonprofit Space Foundation suggested in a 2012 report titled *Pioneering* that NASA administrators should serve renewable terms of five years to prevent an overhaul every time someone new moves into the White House.

The report also argued that scientists and experts should play a stronger role in setting our country's human spaceflight goals, suggesting that the president and Congress appoint an independent commission to approve 10- and 30-year plans developed by NASA. The agency would then submit these plans to Congress for approval every five years. This method closely resembles the way NASA already sets its research goals for physics, earth science, and other fields and allocates the funds allotted from Congress, based on priorities determined through independent surveys conducted every 10 years by the National Academies of Sciences, Engineering, and Medicine.

Such guidelines would also give NASA badly needed financial stability. When Congress resets the agency's funding every year, it plays havoc with space projects that can take a decade to get off the ground. For example, reduced budgets over the past five years have led to delays on new spaceships that NASA is developing with commercial companies to carry astronauts to the space station. The *Pioneering* report advocates that Congress create a fund that the agency can draw from as needed. This would let it spend more in years when large missions are starting up, then bank savings later when costs taper off.

Some of these goals overlap with the Space Leadership Preservation Act, introduced in 2015 by Representative John Culberson of Texas, that was never voted on. It would have created a board of directors to oversee NASA and make its yearly budget requests. That board would have also recommended candidates for NASA administrator to the president, who would then nominate someone from the list to serve a 10-year term. The bill was opposed by House Democrats who objected that board members picked by the president and Congress, using a formula based on which party held majorities in the House and Senate, "would inject partisan politics into that Board."

Although they differ on particulars, this bill, the Space Foundation report and other proposals agree that NASA needs longer-serving administrators and an advisory board to help set its goals based on science. When President Trump and the new Congress take office, they should enact these changes. By giving NASA more independence, they can free it to tackle truly visionary goals whose payoffs lie many years in the future. SA

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Illustration by Scott Park

Nathaniel P. Morris is a resident physician in psychiatry at the Stanford University School of Medicine.

Keep Hospitals Weapons-Free

Tasers and guns issued to security guards do more harm than good

By Nathaniel P. Morris

If you were in a hospital, would you want armed guards roaming the corridors? It is an increasingly relevant question for patients. Today armed guards are becoming more common in health care facilities. According to a 2014 study, 52 percent of hospitals provide handguns for security personnel, and 47 percent have Tasers available. These numbers are considerably higher compared with similar surveys from 2009 and 2011.

Last year this trend drew national attention when the *New York Times* and *This American Life* reported on the 2015 shooting of Alan Pean. Admitted to a Houston hospital during a psychotic episode, Pean was confused, dancing naked and wandering out of his room. After nurses called security for assistance, Pean allegedly assaulted the responding officers. He was shocked with a Taser and then shot in the chest.

Pean survived, but his story raises a question: Why have hospitals taken up arms? Advocates point out that hospitals can be surprisingly violent places. Every year, says the Department of Labor, health care employees suffer 15,000 to 20,000 injuries from on-the-job violence that require time off; the number of serious injuries nearly matches every other industry combined.

In my field—mental health—clinicians are at even greater risk of workplace violence. We often treat patients suffering from psychosis, substance use or other conditions that can cause agitation. I am pursuing residency training in psychiatry, and research suggests that one quarter to one half of my peers will be physically assaulted during our training. So it might make sense then for hospital security guards to have weapons.

Yet as the Pean shooting shows, combining weapons and patient care can have serious consequences. Security officers who might not be trained to deal with symptoms of mental illness can act rashly, harming the very people who came to the hospital for care. These weapons could also get into the wrong hands. As noted in the *Times* article, a 2012 study found that 23 percent of emergency department shootings involved a gun taken from security. In many states, patients have stolen guns from guards and escaped hospitals, terrifying surrounding communities.

Some hospitals use less deadly means, such as Tasers. But these are still dangerous: Tasers can cause cardiac arrest and even death. Their use also raises doubts about the quality of care provided when hospitals resort to electrocuting patients.

Extreme situations that involve active shooters may necessitate the use of weapons to protect hospital patients and staff. But these incidents are rare and unpredictable. Police forces can handle them better than security guards can, and research has not yet shown that arming hospital guards consistently saves lives or improves outcomes for patients.

Meanwhile many in the medical community are decrying the militarization of patient care. In the summer of 2016 the American Medical Association passed a resolution to limit the use of guns and Tasers in health care workplaces. A petition expressing outrage at the 2015 shooting of Pean gathered thousands of signatures, largely from health care workers. Doctors and journalists have called for more research into the risks.

Hospitals might instead employ nonlethal security measures, such as pepper spray or physical restraints. Active shooter plans can prepare hospital staff for emergency situations. For high-risk areas such as emergency departments, some medical centers have installed metal detectors. Clinicians can treat agitated patients with medications, and medical organizations have released guidelines for managing these scenarios.

In 2010 Paul Warren Pardus brought a handgun into Johns Hopkins Hospital in Baltimore. Distraught over his mother's care, he shot a surgeon, his mother and then himself. The doctor survived, but Pardus and his mother died. After unarmed hospital guards and local police secured the scene, Johns Hopkins officials released a statement that included these profound words: "Hospitals are and must remain places of hope and healing that are open to the public. They cannot be turned into armed citadels." I can't help but agree. SA

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Illustration by Ileana Soon

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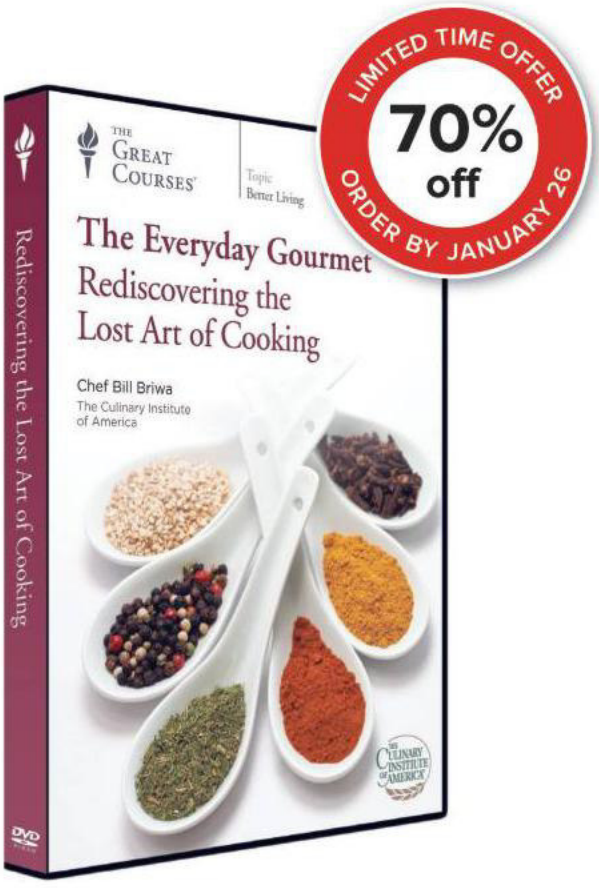

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ADVANCES

Illustration by Thomas Pitilli

INSIDE

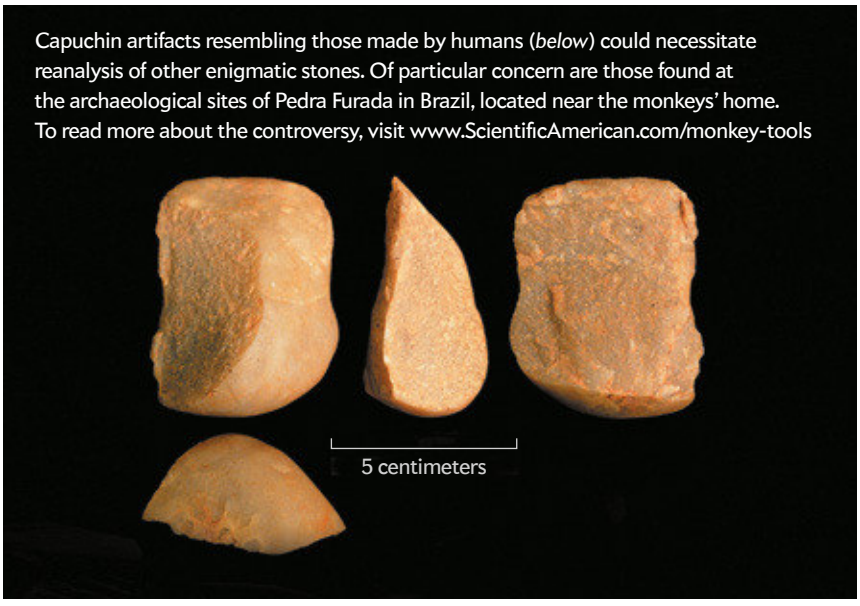
ARCHAEOLOGY

Whose Tools Are These?

Wild monkeys make stone "tools" that bear a striking resemblance to artifacts produced by early humans

A monkey picks up a potato-sized rock in his tiny hands, raises it above his head and smashes it down with all his might on another stone embedded in the ground. As the creature enthusiastically bashes away, over and over, flakes fly off the rock he is wielding. They are sharp enough to cut meat or plant material, but the monkey does not pay much attention to the flakes, save to place one on the embedded rock and attempt to smash it, too. Still, he has unintentionally produced artifacts that look for all the world like stone tools found at some human archaeological sites.

The monkey is a wild capuchin in northeastern Brazil's Serra da Capivara National Park, where these animals have long been known to use rocks for a wide range of activities, from cracking open nuts and digging for roots to catching the attention of potential mates. Other nonhuman primates, including West African chimpanzees, also use rocks as tools in the wild. But the Serra da Capivara capuchins are the only ones that scientists have seen banging rocks together to break them—an activity previously thought to be exclusive to members of the human family. Humans do it to create sharp-edged tools for cutting things. The capuchins, in contrast, have never been seen using the flakes they make; they just



Capuchin artifacts resembling those made by humans (*below*) could necessitate reanalysis of other enigmatic stones. Of particular concern are those found at the archaeological sites of Pedra Furada in Brazil, located near the monkeys' home. To read more about the controversy, visit www.ScientificAmerican.com/monkey-tools

lick the surface of the embedded stone, perhaps in pursuit of mineral dust.

Now a new study has examined the capuchin-produced stone flakes, and it turns out that the chips meet criteria used to distinguish human tools from naturally broken rocks. The findings, published in fall 2016 in *Nature,* could fuel debate over controversial archaeological sites. The discovery also raises questions about what differentiates humans from other primates and how our lineage started fashioning implements from stone.

Tomos Proffitt of the University of Oxford and a group of his colleagues watched the capuchins select rocks to use as hammers and subsequently strike them against cobbles. The researchers retrieved the fragmented stones and also collected other such artifacts found in excavations within the surrounding area—just as they would if they were excavating a human archaeological site. They then analyzed this collection of 111 capuchin artifacts, examining their shapes and sizes, as well as the nature of the scars left on the rocks by all the bashing.

Remarkably, the team found that the capuchin artifacts exhibit distinctive scoop-shaped, or "conchoidal," flaking and sharp edges and that the monkeys often removed multiple flakes from a single rock—all hallmarks of man-made stone tools. (The authors note that stone fragments produced during chimpanzee nut cracking, in contrast, lack most of the diagnostic criteria, as do flakes produced by captive bonobos that have been taught to knap.)

Experts have previously linked such characteristics to the emergence of humanlike hands and coordination and to shifts in human cognition. But the fact that monkeys produced rocks with these same traits demands a different evolutionary explanation. And if modern-day monkeys modify rocks in this way, it is possible that extinct monkeys and apes did, too, leaving behind archaeological assemblages of their own. Archaeologists thus need to refine the criteria they use to identify stone tools intentionally produced by members of the human family, Proffitt and his colleagues argue.

"Many people are going to be disturbed that these tools can be made by capuchins," says archaeologist Sonia Harmand of Stony Brook University, who was not involved in the new research. According to Harmand, the monkey artifacts would not look out of place at East African sites containing tools made by human ancestors in one of the earliest technological traditions: the Oldowan, which dates back to 2.6 million years ago at the site of Gona in Ethiopia. The capuchin flakes resemble the simplest examples of Oldowan technology. But other Oldowan stone tools exhibit considerably more sophistication and planning, she says. The monkey artifacts also diverge from the oldest known stone tools in the world: 3.3-million-year-old implements that Harmand and her team excavated from the site of Lomekwi in Kenya. The Lomekwi tools are far larger and are made of basalt and phonolite—rocks that are denser than the quartz and quartzite rocks the capuchins use.

Some experts wonder whether the capuchins' flakes could spark doubts that members of the human lineage made the oldest stone tools. Although researchers have attributed the tools to human ancestors, the sites lack diagnostic fossils to establish the connection. "We have no clue" who created the material at Lomekwi and Gona, says archaeologist Wil Roebroeks of Leiden University in the Netherlands. Hélène Roche of Paris West University Nanterre La Défense disagrees, writing in a commentary accompanying the *Nature* paper that the capuchin findings should not raise suspicions about who produced the early stone tools found in Africa. Archaeologists have studied hundreds of those sites, she notes—and many of them contain contextual clues, including cut-marked bones that show how tools were used, as well as fossils that indicate human ancestors made them.

Although the capuchin discovery demonstrates that nonhuman species can accidentally produce fragments of rock that look just like human-crafted cutting tools, that does not mean the man-made tools are not special, Harmand cautions. Even if human ancestors started creating flakes unintentionally like the capuchins do, there was something that made them realize they could put them to use and even make new tools to suit their purposes. Moreover, human technology evolved from the comparatively simple tools seen at Lomekwi and at Oldowan sites to hand axes with carefully shaped cutting edges a million years later and eventually to the elaborate machinery we have today. Why did technology fail to evolve to the same degree in chimps and monkeys? Harmand asks. Why did humans alone take it to such an extreme?

Proffitt is eager to determine how long capuchins have been using rocks this way. Other evidence demonstrates that they have been using the cobbles to crack open nuts for at least 600 years. And chimpanzee stone tools from the Ivory Coast in West Africa date back to 4,300 years ago. Beyond that, "we have no evidence of what ancient monkeys or great apes were doing," Harmand observes—which leaves plenty of room for more surprises in the future.

—Kate Wong

FROM "WILD MONKEYS FLAKE STONE TOOLS," BY TOMOS PROFFITT ET AL., IN *NATURE*, VOL. 539; NOVEMBER 3, 2016

PUBLIC HEALTH

STDs on the Up

Reported cases of sexually transmitted diseases hit an all-time high in 2015, according to a new report from the U.S. Centers for Disease Control and Prevention, which tracks the three most common STDs: chlamydia, gonorrhea and syphilis. The CDC attributes the upswing to an erosion of public prevention resources and treatment services, as well as increased screening. An increase in online dating may also contribute, especially for young men who have sex with men, says Eric Schrimshaw, a professor at the Columbia University Mailman School of Public Health. Schrimshaw thinks more extensive and comprehensive sex education, along with better community services, could most effectively overturn the trend. At their worst, STDs can cause infertility, cancer and death—and their spread can lead to antibiotic resistance. *—Ryan F. Mandelbaum*

BY THE NUMBERS

110 million
Estimated total number of STD infections in the U.S.

478.8
Chlamydia cases per 100,000 people

5.9%
Increase in chlamydia cases from 2014 to 2015—an all-time high

12.8%
Rate increase in gonorrhea

19%
Rate increase in syphilis

$16 billion
Annual cost of treating STDs

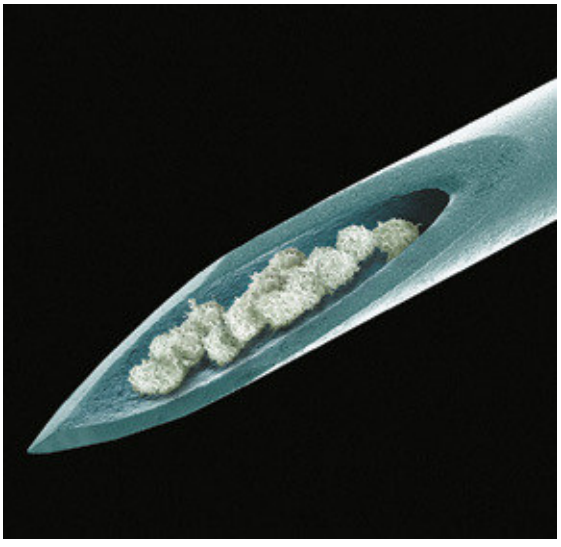
SOURCE: *SEXUALLY TRANSMITTED DISEASE SURVEILLANCE 2015*. U.S. CENTERS FOR DISEASE CONTROL AND PREVENTION, OCTOBER 2016

HEALTH

Could a Special Diet Replace Chemotherapy?

For patients with blood cancer or in need of a bone marrow transplant, the amino acid valine could hold answers to new treatments

Blood cancer treatments may one day include special dietary restrictions: researchers have found that an essential amino acid plays a crucial role in the creation of blood stem cells—a discovery the scientists say could lead to a potential alternative to chemotherapy and radiation.



In 2014 about 20,000 people underwent bone marrow (*above*) or umbilical cord blood transplants in the U.S.

Valine is one of 10 essential amino acids—protein building blocks that are crucial to life but cannot be made by the human body. It must therefore be obtained through diet and is found in protein-rich foods such as meat, dairy and legumes. Valine is involved in metabolism and tissue repair, and now it also seems key to the formation of blood stem cells. As reported in *Science,* researchers at the University of Tokyo and Stanford University found that human blood stem cells failed to proliferate when cultured in petri dishes without valine. Mice deprived of the amino acid for two to four weeks also stopped making new red and white blood cells.

Based on these results, senior author Hiromitsu Nakauchi and his colleagues think that depriving blood cancer patients of dietary valine before a bone marrow transplant might spare them the necessity of chemotherapy or radiation—both of which destroy cancer-causing blood stem cells to make room for transplanted ones but carry health risks. In a follow-up experiment, Nakauchi and his colleagues put the idea to the test in valine-restricted mice and were able to successfully transplant bone marrow without needing radiation or chemotherapy. But half of the mice died from a lack of valine shortly after the four-week trial ended.

Nakauchi says it will take much more research to determine how long people can tolerate a valine-free diet (which would likely be supplied intravenously). But if the deprivation works in humans, it could open up the possibility of bone marrow transplants for some patients—such as pregnant women or people with low blood counts—who are usually not considered candidates for chemotherapy or radiation, says Linheng Li, a stem cell biologist at the Stowers Institute for Medical Research in Kansas City, Mo., who was not involved in the work. He suspects that this approach will need to be combined with other therapies or smaller doses of chemo and radiation to be effective, though.

Removing valine from the diet of certain leukemia patients could also potentially eliminate the cells that are the cause of their cancers in the first place, Nakauchi says: "If such a simple and relatively less harmful therapy could be used to treat leukemias, that would be great."

—Karen Weintraub

STEVE GSCHMEISSNER *Science Source*

ECOLOGY

Bats in the Bronx

Green roofs in Gotham are bat signals—but not for Bruce Wayne

For years cities have encouraged residents to install green roofs—gardens that turn barren tar and asphalt roofs into verdant oases. The added foliage helps to keep buildings cool in the summertime and warm in the winter; it can also ease sewers by absorbing rainfall. But not just the hardscape benefits from these lush areas—so do some urban dwellers: bats.

"The general population of New York City, they see birds; they see insects. Occasionally they see fish," says Kaitlyn Parkins, an ecologist at the Lower East Side Ecology Center. "But very rarely will a New Yorker tell you that they've seen a bat."

In fact, six native bat species flit amid the city's canyons of glass and steel—and they need places to roost and insects to eat. Research suggests that rooftop gardens are an excellent dining option because they support robust bug populations. "Lots of insects come in with the green roof material," Parkins says. "But bugs are also pretty good at dispersing from nearby parks and other areas onto green roofs." So in 2012 and 2013 Parkins (then at Fordham University) and her colleagues placed ultrasonic recorders on four barren rooftops and four others covered with vegetation to listen for the flying mammals' high-pitched chirps and squeaks. Although they detected bats over both roof types, they recorded twice as much activity on average over the green roofs. Software analysis of the squeaks indicated that the most common species was the tree-roosting eastern red bat.

The latest of the team's two studies was recently published in *Urban Naturalist*, and Parkins says that together, these studies show that green roofs are increasingly providing critical habitat for a broad array of species. She adds that green roofs cannot replace parks or other green spaces on the ground as ways to maintain urban wildlife. But they are a way of expanding habitats without taking up additional real estate, notes Joseph Duchamp, an associate professor of ecology at Indiana University of Pennsylvania, who was not involved with this project. Not to mention that bats lured by rooftop buffets may help keep pest numbers down at ground level—some can eat up to 1,000 mosquitoes an hour.

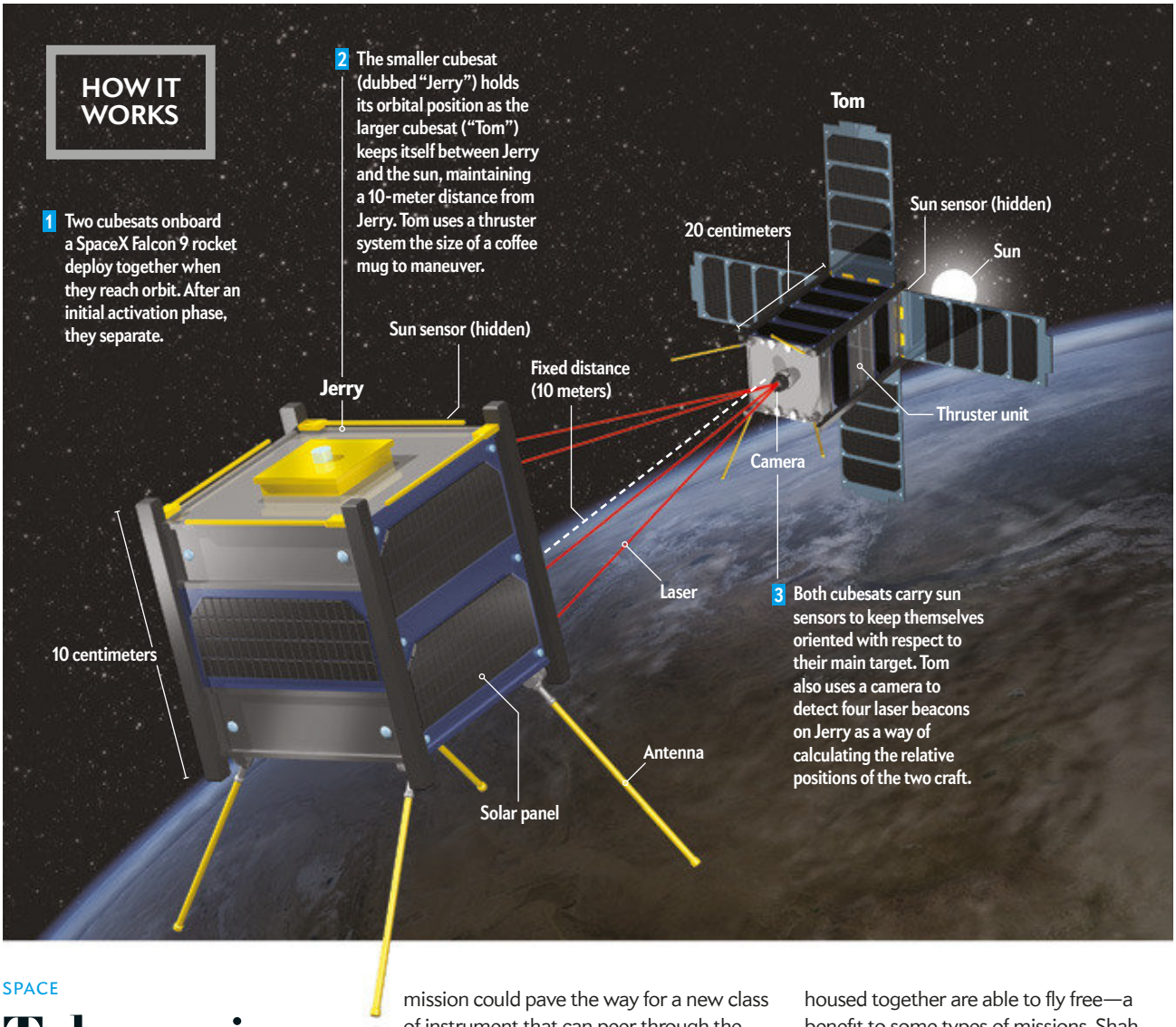
For now Parkins has a tip for New Yorkers: "Look up." —*Kendra Pierre-Louis*

1

2

New York City's green roofs (*1*) may appeal to bats, such as the eastern red (*2*), because they are home to insects and spiders.

VALERY RIZZO Getty Images (1); JOEL SARTORE Getty Images (2)



SPACE

Telescopic Tag Team

NASA works on building a gigantic space telescope from two miniature satellites

More than 400 years after Galileo handcrafted his first spyglass, NASA and South Korea's Yonsei University aim to create a "virtual" telescope in space by using two separate spacecraft. To test the concept, scientists have built two small satellites called cubesats that will practice lining up in orbit to construct a single telescope with a focal length as large as the distance between them. Scheduled for launch in early 2017, the roughly $1-million mission could pave the way for a new class of instrument that can peer through the sun's glare or at distant alien planets, without requiring a massive single scope.

The six-month mission—called "CubeSat Astronomy by NASA and Yonsei using Virtual telescope ALignment eXperiment" (CANYVAL-X)—will try out a technique for forming a telescope that would otherwise be much heavier to launch. The plan requires two spacecraft (together the size of a bread loaf) to orbit together in a straight line, always pointed at their target. "Flying two spacecraft in coordination, aligning them to a distant source and holding that configuration is a capability that has never been attempted," says Neerav Shah, an aerospace engineer at the NASA Goddard Space Flight Center.

Virtual telescopes could come in handy because components that would usually be housed together are able to fly free—a benefit to some types of missions, Shah explains. For example, an instrument on one satellite could block the glare of the sun or a distant star, making it possible for a camera on the other to image faint objects such as the sun's ghostly corona or exoplanets orbiting a star. Other telescopes designed to detect high-energy wavelengths, such as x-rays, need considerable distance between their mirrors and x-ray detectors and therefore must be built at large scales—an expensive venture in terms of construction and launch.

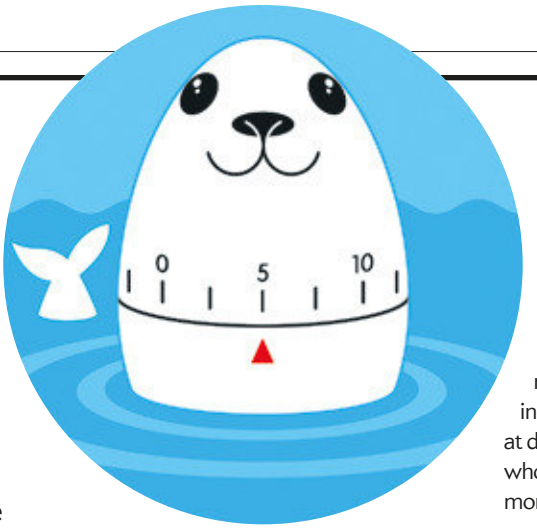
CANYVAL-X will not carry all the components necessary for a working scope but aims to demonstrate that the concept is possible. A $110-million European Space Agency mission called Proba-3 is slated to fly a fully functional virtual telescope pointed at the sun in 2019. —*Jeremy Hsu*

Illustration by Don Foley

ANIMAL BEHAVIOR

The Remarkable Timing of Seals

Some marine mammals can compare time periods and sense milliseconds of difference



Many animals follow daily schedules or seasonal cycles—but can they distinguish, say, three seconds from 13? Some—bumblebees, pigeons, cats and others—are known to perceive passing time with some precision. After years working with the captive seals at the Marine Science Center at Germany's University of Rostock, biologist Frederike D. Hanke suspected the slippery mammals might be able to as well.

Hanke and her team tested her hunch on Luca, an 11-year-old harbor seal at the center. They displayed a white circle on a black computer screen for a period of three to 30 seconds, paused and then flashed the circle again. The researchers trained Luca to press one button if he thought the second display was longer and another if he thought both displays were of equal length. When he was correct, he enjoyed a tasty herring treat.

The team found that Luca could detect differences as short as 420 milliseconds. In other words, he could distinguish a three-second display from one lasting 3.42 seconds. His precision weakened as the pairs of display durations got longer, however. The experiment's results were recently published in *Animal Cognition*—the first time the ability to measure time has been reported for a pinniped.

Seals may have evolved this skill to make split-second decisions while chasing fish or to identify vocalizations made at different rates by other seals, says Hanke, who is extending her investigation both to more seals and to acoustic stimuli.

Peter Cook, a psychologist at New College of Florida who has studied pinniped cognition and was not involved in Hanke's work, was most impressed by how easily Luca learned the testing task. It is common in psychophysics experiments such as this one for animals to need lots of practice—but Luca learned it in two training sessions. "Even though we're talking about very small discriminations, these short durations really pop for the seal," he says. "It strongly suggests this is a very robust and well-tuned sense." —*Jason G. Goldman*

Illustrations by Thomas Fuchs

BIOLOGY

Veggies with Vision

Do plants have the ability to see?

Don't look now, but that tree may be watching you. Several lines of recent research suggest that plants are capable of vision—and may even possess something akin to an eye, albeit a very simple one.

The idea that plants may have "eyes" is, in a way, nothing new. In 1907 Francis Darwin, Charles's son, hypothesized that leaves have organs that are a combination of lens-like cells and light-sensitive cells. Experiments in the early 20th century seemed to confirm that such structures, now called ocelli, exist, but the concept of a "seeing plant" fell by the wayside—only to reemerge in the past few years.

In a recent issue of *Trends in Plant Science,* František Baluška, a plant cell biologist at the University of Bonn in Germany, and Stefano Mancuso, a plant physiologist at the University of Florence in Italy, lay out new evidence for visually aware vegetation. To make their case, the researchers first point to the 2016 discovery that *Synechocystis* cyanobacteria, single-celled organisms capable of photosynthesis, act like ocelli. "These cyanobacteria use the entire cell body as a lens to focus an image of the light source at the cell membrane, as in the retina of an animal eye," says University of London microbiologist Conrad Mullineaux, who helped to make the discovery.

Although researchers are not sure what the purpose of this mechanism is, its existence suggests that a similar one could have evolved in higher plants. "If something like this is already present at the lower level of evolution, it is most likely kept," Baluška says.

Recent work also shows that some plants, such as the cabbage and mustard relative *Arabidopsis,* make proteins that are involved in the development and functioning of eyespots—the ultrabasic eyes found in some single-celled organisms such as green algae. These proteins specifically show up in structures called plastoglobuli, which are famed for giving autumn leaves their red and orange hues. "This discovery suggests that plastoglobuli in plants may act as eyespots," Baluška says.

Other observational research reveals plants have visual capabilities we just do not understand yet. For instance, as reported in 2014 in *Current Biology,* the climbing wood vine *Boquila trifoliolata* can modify its leaves to mimic the colors and shapes of its host plant.

> The concept of a "seeing plant" fell by the wayside—only to reemerge in the past few years.

Although the evidence for eyelike structures in higher plants remains limited, it is growing. "I had never heard about plant vision, and I would have dismissed it as unlikely until my own discovery of cyanobacteria acting as a camera eye," says biotechnologist Nils Schuergers, co-author of the 2016 study on *Synechocystis.* The next challenge is to confirm the early 20th-century experiments showing that plant cells themselves can act like lenses—and researchers still need to figure out all the ends to which plants put their rudimentary sight. —*Marta Zaraska*

Q&A

Hidden Side Effects

Researchers don't always share the whole picture when it comes to the safety of drugs and other medical treatments

Approximately half of studies published on new medical treatments leave out at least some of the adverse effects they uncovered, according to a recent analysis in *PLOS Medicine.* A team of British researchers conducted the review after coming across individual cases of missing side effects in medical literature, which includes studies from pharmaceutical companies, hospitals and academics. To determine how widespread the problem was, they analyzed 28 journal articles that together cross-checked the published data from more than 500 clinical studies with their original data sets. The review's results quantitatively confirm that some drugs may have side effects not even doctors know about—which means treatments may not be as safe as they appear, says Yoon Loke (*above*), a physician and lecturer at the University of East Anglia in England. SCIENTIFIC AMERICAN talked with Loke about the importance of clinical data transparency. Edited excerpts follow. —*Ryan F. Mandelbaum*

SCIENTIFIC AMERICAN: Why are these results troubling?

Yoon Loke: What we found confirmed our suspicions: missing data are very common. Journal publications often report a smaller proportion of the measured adverse events than were observed in the clinical research. We found it alarming. You want to do the best for the patient, but if you can access only half the information, then a decision on choosing a particular drug or device might not be as reliable as you'd like.

Why do adverse events go unreported?

I think one of the problems is that journals

COURTESY OF YOON LOKE

DWIGHT ESCHLIMAN *Getty Images*

DATA SHOULDN'T DISAPPEAR

Starting this month, U.S. investigators conducting clinical trials will have to make all their findings publicly available—no matter what outcome a study has—thanks to a new rule from the U.S. Department of Health and Human Services and the U.S. National Institutes of Health. Meanwhile the Evidence-Based Medicine Data Lab at the University of Oxford released a new online tool called TrialsTracker that reveals exactly who is withholding data. *—R.F.M.*

are limited by space and the scope of what they can publish. I myself was an editor of a scientific journal, and often you want to publish interesting, positive things that people want to read. It's an optimism bias. There are a lot of other issues that have been hinted at, too. For example, for a company to market a product, it may be more beneficial to publish more favorable results, as opposed to adverse events.

What can patients do?

If you are a patient and take part in a clinical trial, when you sign the consent form you should be able to stipulate that you want the results of the study to be available to the public. On Alltrials.net, a large body of people are campaigning for all trials to be registered and all results to be reported so there aren't so many missing data. I'm hoping that through the public voice—as well as the U.S. Food and Drug Administration recently tightening up their regulatory requirements—data about adverse events will become available to a much wider audience.

IN THE NEWS

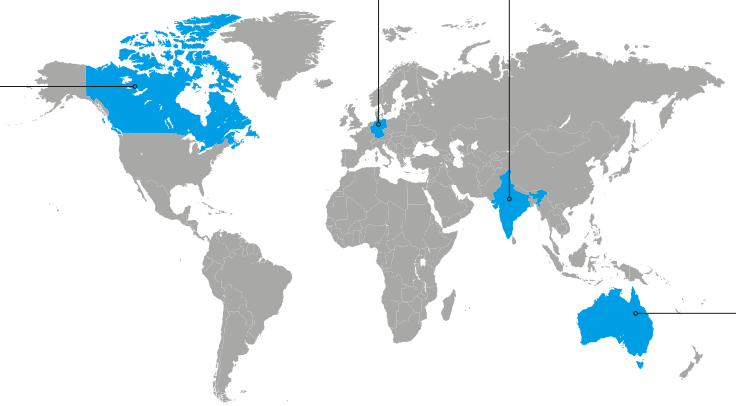
Quick Hits

GERMANY

Rail company Alstom unveiled a train powered by hydrogen fuel cells. Scheduled to begin service as early as 2018, the emissions-free train can carry 300 passengers and travel at speeds as fast as 140 kilometers per hour.

INDIA

Farmers and environmentalists submitted a petition protesting the Indian government's approval of mustard plants that have been genetically modified (GM) to tolerate herbicides. The protesters worry the strain will benefit only seed sellers and that herbicides could displace rural workers in charge of manual weeding. Mustard would be the first GM food crop in the country.



CANADA

Prime Minister Justin Trudeau announced a minimum tax on carbon emissions of $7.62 per metric ton. The tax is set to begin in 2018 and will increase to $38.11 per metric ton by 2022.

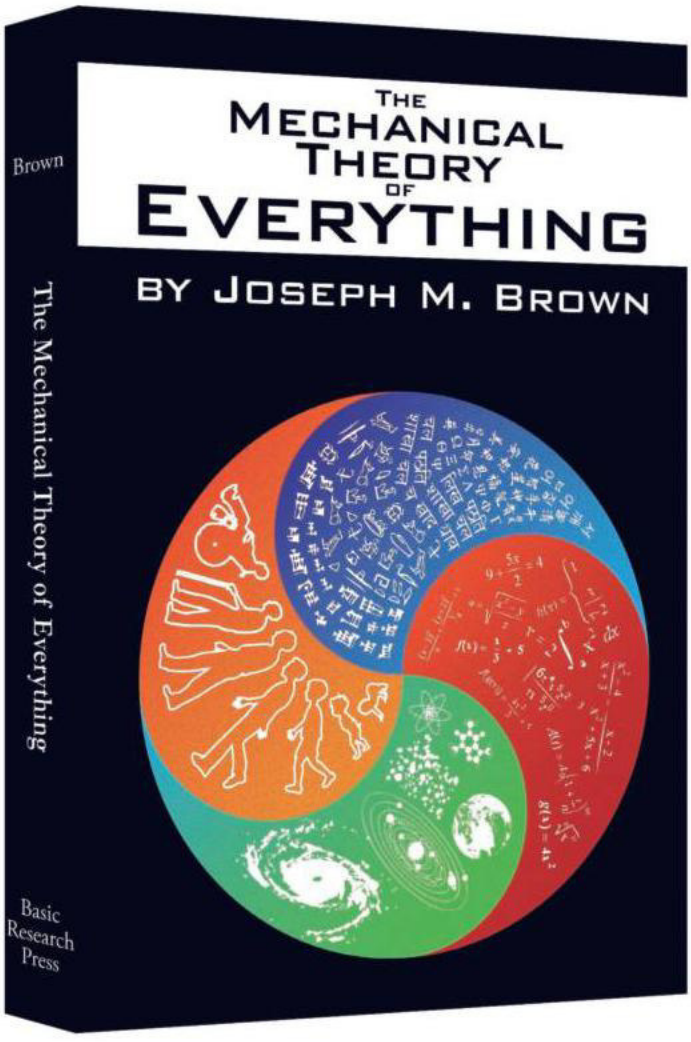
AUSTRALIA

Paleontologists discovered a new species of dinosaur, *Savannasaurus elliottorum*, in Queensland. The 12- to 15-meter-long sauropod lived on the continent an estimated 95 million to 98 million years ago. Dinosaur remnants on the giant island are rare: in total, no more than 12 skeletons and a handful of single bones have been found.

ANTARCTICA

Twenty-five nations reached an agreement that has created the world's largest marine sanctuary off the coast of Antarctica. First proposed in 2011, it covers 598,000 square miles of ocean.

For more details, visit
www.ScientificAmerican.com/jan2017/advances



- Everything consists of small spherical particles.
- All forces are due to collisions of these particles.
- The second law of thermodynamics is not universally valid.
- Newton's laws are universally valid.
- All matter at rest consists of spherical condensations of the basic particles. These condensations travel in circular paths at the speed of light.
- Matter moves by being impacted by mass which causes the circulating mass to move in a plane spiral path – always at the speed of light.
- The Schrödinger Equation gives the particle paths, and the equation comes from Newton's equation F=ma.
- The Universe is not expanding.
- Dark matter, stars, and planets come from the explosion of a super giant Neutron Star.
- Dinosaurs were killed by a sudden increase in gravity caused by a sudden contraction of the Earth.
- Human aging Is caused by torsional strain increases at each division of DNA.
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Dina Fine Maron is an associate editor at *Scientific American*. She wrote in the October magazine about personalized genetic medicine and tests to avoid dangerous drug reactions.

Cold Comfort

The case for supercooling the entire body to treat conditions ranging from achy joints to sagging skin rests on thin ice

By Dina Fine Maron

The day Phil Mackenzie decided to expose his almost naked body to gas colder than the lowest natural temperature ever recorded on Earth started like any other day. The professional rugby player woke up and headed to the playing field in Manchester, England, for his usual grueling workout. He ran passing and kicking drills. He was repeatedly tackled. He lifted weights. By the end of practice he was exhausted. Usually Mackenzie would head back to the locker room and soothe his sore body with a hot shower. On this day, however, an enclosed pod resembling a massive standing tanning bed beckoned from the nearby parking lot. Mackenzie and a couple of his teammates stepped inside. Frigid gas started to swirl around them.

Mackenzie had wanted to try this procedure, called whole-body cryotherapy, specifically to ease his achy joints. But he says that after receiving multiple two-minute sessions spread out over several days he saw other benefits, too. "I felt refreshed right away. My sleep was better," he recalls. Soon the treatments became routine: Mackenzie would go four times a week to chill out amid the icy vapors, wearing nothing but his spandex shorts, gloves, socks, slippers and headband to protect against frostbite. Most of his teammates also adopted the regimen. In fact, there was usually a line for the pod after practice.

Mackenzie and his fellow rugby players are hardly the only devotees of cryotherapy. Star athletes, including Kobe Bryant and LeBron James, have turned to it. Reportedly, Hollywood A-listers such as Daniel Craig and Jennifer Aniston have, too. The market for these devices is beginning to burgeon in the U.S., with sports teams snapping them up to condition their players and spas and wellness centers installing them for clients looking to relax, lose weight and fight signs of aging. One large U.S. distributor of whole-body cryotherapy machines, Dallas-based CryoUSA, says it has installed more than 200 units across the country since 2011, half of them in 2015. The company expects that the 2016 tally will show an even sharper uptick in sales.

Yet the science behind these devices is decidedly lackluster. In July the U.S. Food and Drug Administration issued a warning stating that there is no evidence these technologies help to ease muscle aches, insomnia or anxiety or provide any other medical benefit. Instead, it said, they may cause frostbite, burns, eye damage or even asphyxiation. In a statement to *Scientific American* the agency added, "The FDA has not approved or cleared any whole-body cryotherapy devices, and we do not have the necessary evidence to substantiate any medical claims being made for these devices." The agency based its warning on its own informal review of published literature and generally recognized hazards associated with exposure to the gas that creates the cold conditions in the treatment chamber. Adding insult to injury, cryotherapy is pricey. A package of five two-minute sessions can cost several hundred dollars.

A CHILL IN THE AIR

THE NOTION OF SUPERCOOLING the entire body for therapeutic reasons got its start in Japan during the late 1970s, when it was touted as a potential way to relieve joint pain in patients with multiple sclerosis or rheumatoid arthritis. It then gained traction in western Europe in the 1990s. Only recently, in the past decade, has it risen to prominence in the U.S. and Australia. As the practice has spread, the list of ailments that it can supposedly address has exploded. According to the latest marketing claims, it can treat not only pain but conditions ranging from asthma to Alzheimer's disease.

The logic of whole-body cryotherapy stems from the widely accepted science underlying standard-issue cold therapy, which uses ice packs and ice-water baths to treat acute soft-tissue injuries. Doctors will typically recommend icing as part of a care regimen for a sprained or strained ankle, for example. Clinical studies have found that applying ice to an injury site for some five to 15 minutes can lower skin temperature to less than 55 degrees Fahrenheit, which slows and thus dulls pain signals from affected nerves. Ice may help in another way, too. Animal studies sug-

Illustration by Ryan Garcia

gest that it combats inflammation after injury by decreasing the number of white blood cells moving to the injury site, among other mechanisms, says Chris Bleakley, a sports medicine researcher at Ulster University in Northern Ireland. (Prolonged inflammation can extend pain, decrease range of motion and impair the blood flow around the damaged area.)

But whether cryotherapy can actually produce those same benefits is uncertain at best. Unlike run-of-the-mill cold therapy, it uses gasified liquid nitrogen to cool the air around recipients who stand in an enclosed chamber to temperatures below –200 degrees F. Although the gas temperature is much colder than ice, the cold from ice applied directly to the body has a better chance of penetrating through layers of skin and fat to reach the target soft tissue than does icy gas that swirls around the skin but is not pressed against it, making chilling of deeper parts of the body harder to achieve.

Indeed, a 2014 analysis of preexisting ice, cold-water and whole-body cryotherapy studies, carried out by Bleakley and by other researchers, found that ice packs delivered the biggest reductions in skin temperature and intramuscular temperature: a 10-minute ice-pack application cooled skin between 32 and 47 degrees F, for example. Three minutes of whole-body cryotherapy, however—the average time manufacturers recommend to protect user safety—resulted in a lesser reduction, ranging between six and 35 degrees F.

Because whole-body cryotherapy is not as effective at cooling intramuscular temperatures, it is unlikely to slow pain signals as effectively as ice does or to cool soft tissues enough to quell inflammation, Bleakley says.

Other studies compound these doubts. In the gold standard approach to evaluating efficacy of a given therapy, participants are randomly designated to receive the treatment in question, a different one or none at all. To date, researchers have conducted four such randomized control trials of whole-body cryotherapy. In an exhaustive examination of those studies, exercise physiologist Joe Costello of the University of Portsmouth in England, along with Bleakley and others, found no significant benefit to the treatment. "There is insufficient evidence to prove whether whole-body cryotherapy reduces muscle soreness or improves recovery after exercise compared to … no intervention," he states.

Those four trials, as well as Costello's assessment of them, are not the final word. They were very small, totaling just 64 subjects. And because all but four of the subjects were men, with an average age in their early 20s, it is impossible to say whether the putative panacea might affect women or older people differently.

UNANSWERED QUESTIONS

THE SHORTCOMINGS OF THESE TRIALS are emblematic of the poor state of the science of whole-body cryotherapy. Most studies of the treatment involve "very small numbers" of participants and have "methodological flaws" such as the lack of a control group, Bleakley says. "Sports scientists really need to pick up this area and align it with the quality of studies in wider medicine," he asserts.

As for the effects of whole-body cryotherapy on all the other ailments it can purportedly address beyond athletic injuries, the science is virtually nonexistent. The claims have not been subjected to the rigors of a randomized trial. Nor do researchers have definitive answers about whether exposure to gasified liquid nitrogen produces beneficial effects on heart rate, blood pressure or metabolism—effects that, if they occurred, might help ease anxiety, treat migraines or fuel weight loss, among other aims.

Mark Murdock, managing partner at CryoUSA, does not dispute that whole-body cryotherapy lacks evidence for many of the uses claimed for it. The company promotes the devices for reducing pain and inflammation and increasing energy, but in his view, that use provides "comfort," not medical assistance. He adds that medical claims, such as that the devices can drive weight loss, are "crazy." He also says he supports the FDA's decision to release the warning it issued in July and thinks the agency should ultimately step in to regulate the industry and curb such assertions.

Not only are the supposed benefits of cryotherapy chambers unproved but scientists also lack a clear understanding of any risks they might pose. No studies have focused on adverse effects. And not all whole-body cryotherapy is created equal: treatments vary in duration, temperature and which body parts are spared contact with the subzero vapors. How long a person is exposed, at what temperature and under what conditions matter for safety, says Naresh Rao, the USA Water Polo Olympic team's physician.

Nevertheless, the notion of treating what ails us with a stint inside a glorified freezer has a powerful allure. Recipients report positive effects anecdotally, but the lack of evidence to support these claims suggests they may simply stem from belief in the treatment—the placebo effect. Rao, who is also a doctor of osteopathy (a field that supplements traditional medical care with holistic treatments), says that although he would not choose cryotherapy as first-line treatment for injured athletes, he supports his patients who want to use it—even if the benefits are subjective at best. Yet, he notes, "I do think it needs to be medically regulated. I wouldn't say it's ready for a consumer coming off the street." People with heart issues or uncontrolled hypertension, for example, should not seek out cryotherapy, he warns, because sudden exposure to such cold temperatures could trigger heart attacks or other serious health complications in these individuals.

Some researchers are still hoping for good news about cryotherapy's efficacy. Rebeccah Rodriguez, a Science Board member of the President's Council on Fitness, Sports & Nutrition, an osteopath and the physician for the San Diego Breakers rugby team, is among them. She plans to start a study in 2017 focused on evaluating cryotherapy chambers for facilitating recuperation from concussions. And a research team in Marseilles is conducting a preliminary study to assess whether whole-body cryotherapy has anti-inflammatory effects that could make it a viable alternative to popping traditional nonsteroidal anti-inflammatory drugs (known as NSAIDs).

"There is much work to be done," Ulster's Bleakley says. Only large randomized controlled studies can gauge the efficacy of whole-body cryotherapy—and arm consumers with the cold, hard facts. SA

Your E-mail Password Will Never Be Safe

A long list of corporate and political hacks has made that very clear

By David Pogue

Hillary Clinton lost the election in November, and a major reason was probably because of one of humankind's most flawed creations: e-mail.

She was dogged, of course, by her use of a private server during her tenure as secretary of state. But her campaign was also weakened by a steady stream of hacked e-mails, not always flattering, especially those of the Democratic National Committee and of her campaign chair, John Podesta.

Those weren't the first damaging e-mail leaks in history, of course. You may remember "Climategate," the 2009 leak of climate scientists' e-mails, which, according to critics, revealed a conspiracy to exaggerate the climate crisis. Or the 2014 hack that made e-mails and other documents from Sony Pictures Entertainment public, with devastating personal, professional and corporate consequences. Multimillion-dollar movies were canceled, a top executive lost her job and relationships were shattered.

And then there was LinkedIn, hacked in 2012 (165 million customer records accessed), Evernote in 2013 (50 million), Target in 2013 (110 million), Home Depot in 2014 (56 million credit cards; 53 million e-mail addresses), my employer, Yahoo, in 2014 (500 million), Anthem in 2015 (80 million).

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

Since 2005, corporate systems have been breached more than 5,100 times, involving nearly a billion records. And the breaches are getting bigger and more frequent. For years experts have been giving the same advice for keeping our digital lives secure: Use complex passwords. Change them often. Don't use the same password for more than one service. Some of us do that; most of us don't. But you know what? It doesn't matter.

In almost every hacking case, it didn't matter if your password was "password" or "k&1!#_qw<>poi23@37!j"—your data were swiped. You were a good little password soldier, and you got hacked anyway. These big corporate hacks don't necessarily come about from bad guys guessing our passwords.

The Target hack, for example, relied on malware that recorded customers' swipes in the stores' credit-card readers. The 2014 leak of Hollywood starlets' nude photos was the product of a phishing scam. (The hacker sent the actresses phony "account problem" e-mails; when they clicked the link to fix the problem, they landed on a *fake* login site—and thereby provided their passwords to the hacker.) Staffers for both Podesta and the DNC lost their passwords to phishing scammers, too.

Having good, long, complex passwords wouldn't have helped in any of those cases. Dear reader: It's time to admit it. We've lost this battle. We should accept that data breaches aren't shocking aberrations anymore—they're the new normal. The age of reliable security is gone. We need to adjust our thinking. E-mail will never be completely secure for everybody. Go ahead, get started on the stages of grasping this new reality: denial, anger, bargaining, depression, acceptance.

Actually e-mail was never *intended* to be secure. Most messages are sent as plain, easily readable, unencrypted text from your sending device to your e-mail service (Gmail or whatever), to your recipients' e-mail services, and from there to *their* devices. Encryption is a rare, partial and inconvenient solution.

There are ways to communicate securely, of course. You could use, for example, an encrypted chat program such as Cryptocat, ChatSecure or PQ Chat. But that approach isn't the solution, because the same app has to be on both ends of the conversation. As a result, those chat programs will never be as universal as e-mail.

There are "unhackable" services, too, with names like Tutanota and Posteo. But there's a charge to use them—so once again, they'll never become universal. If you're not a celebrity or politician, your greatest source of protection is your own obscurity. Frankly, the hackers are generally uninterested in getting into the e-mail of nobodies. So there's that consolation.

No matter who you are, the only surefire advice is to heed the joke that's been popping up online lately: "Dance like no one is watching. E-mail like it's going to be read aloud in a deposition." SA

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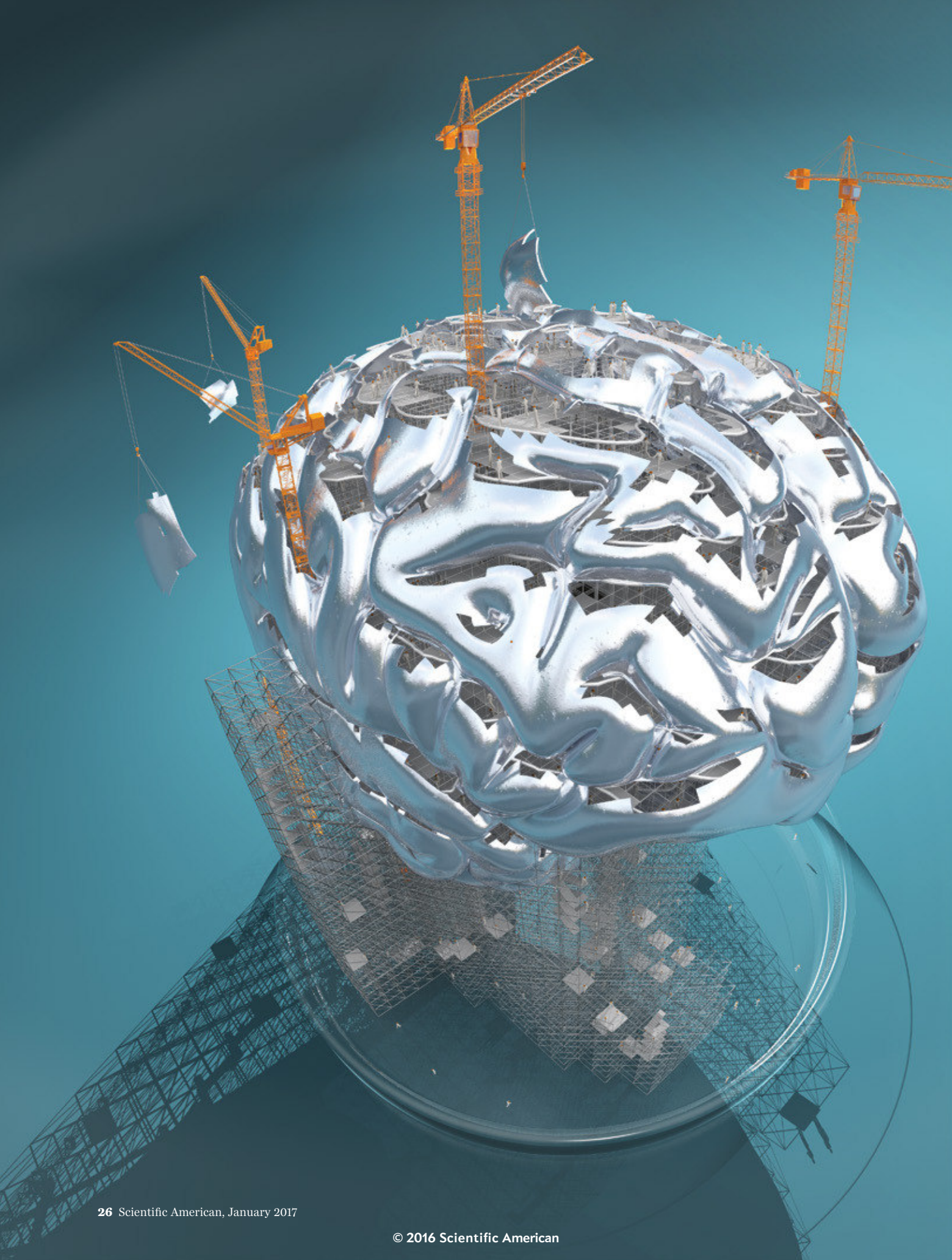


"What I cannot create, I do not understand."

—Richard Feynman, 1988

NEUROSCIENCE

LAB-BUILT BRAINS

Scientists copy nature's most complex organ in the hope of solving the mysteries of brain disorders, from autism to Alzheimer's

By Juergen A. Knoblich

Illustration by Bryan Christie

Juergen A. Knoblich is a senior scientist and deputy scientific director of the Institute of Molecular Biotechnology of the Austrian Academy of Sciences in Vienna. He studies neural stem cells and the development of the fruit fly nervous system.

EVERYTHING THAT MAKES US HUMAN IS LOCATED WITHIN 1.4 KILOGRAMS OF YELLOWISH tissue composing the human brain. It is here that our thoughts develop, here that we feel love or hate, and where the most creative and most evil ideas of humankind arise. This walnut-shaped structure is also the most complex organ nature has generated. The brain harbors about 86 billion neurons, or nerve cells, that have to be born at the right time, migrate to the right place, and wire up in the right way if we are to survive and thrive.

Understanding exactly how the human brain develops and functions is the greatest challenge of modern biology. Most of what we have learned about the organ since the birth of neuroscience more than 100 years ago derives from experiments done on animals—frequently mice or rats. Scientists could justify this approach because mice and humans share a common brain architecture: they harbor many of the same types of nerve cells and rely on essentially the same parts of the brain to carry out shared mental processes. But humans and rodents differ in one key way. Whereas the mouse brain has a smooth surface, the human brain is highly folded.

To nonscientists, this difference might seem trivial. But neurobiologists believe that the folding makes a world of difference to human brain function. It allows for many more neurons to be placed within the same volume and is also a prominent feature of all "intelligent" animals, such as monkeys, cats, dogs and whales. Evolutionary biologists have shown that folding arose from another difference between mice and people: neurons in many parts of the brain arise from a specific set of precursor cells that exist only in minute numbers in mice.

Such differences may explain why many common genetic mutations responsible for severe neurological disorders in humans have little effect when bred into mice by researchers trying to study the mechanisms of human diseases. If the mutations affect the development or maintenance of proper human brain architecture or the functioning of cell types that are common only in humans, then the studies would be doomed to failure. In fact, the unique characteristics of the human brain may be one of the reasons that rodent studies have yielded no effective therapies for such brain disorders as schizophrenia, epilepsy and autism.

Recognition of the differences between mouse and human brains has spurred a hunt for more informative ways to conduct neuroscience experiments. Recently my laboratory has come up with an exciting approach: growing the largest part of the developing brain in miniature in a lab dish. These brain structures, called organoids, give neuroscientists a model of the human brain that should provide information they cannot obtain by running studies in mice. Researchers can observe what happens when the brain-in-a-dish, or mini brain, is exposed, for example, to the Zika virus, which can disrupt brain development in fetuses of infected women, or when an organoid is genetically engineered to mimic a brain afflicted with a neurological disease.

BRAIN-IN-A-DISH (SORT OF)

MY LAB BEGAN WORK on organoids in 2012, when Madeline A. Lancaster, then a postdoctoral scientist in the group, devised a way to replicate in a culture dish the essential processes that lead to brain formation in a human fetus during the first roughly 10 weeks of development [*see box on opposite page*]. Our procedure relies on human cells known as stem cells, which exhibit a remarkable feature called pluripotency. Pluripotent stem cells are the same type of cells found in the early embryo. When cultured under the right conditions, they can give rise to any kind of tissue, be it nerve, muscle, blood, bone or any other type. In the fetus, these new cells retain their pluripotency for only a few days. But using special lab cultures, researchers can preserve them in this state permanently and ultimately turn them into almost any desired cell type.

To start, we culture the cells in a liquid containing all the nutrients needed for growing the neuroectoderm, the part of a fetus that forms the nervous system. When the cells aggregate into a ball called an embryoid body, we embed the ball in an

IN BRIEF

Knowledge about the human brain often derives from experiments performed on mice, rats or other animals. Brains of these species share much in common with the human organ, but they lack a highly folded surface, a difference that affects neural functioning.

Unique qualities of the human brain may help explain why rodent studies have failed to yield new treatments for brain disorders ranging from schizophrenia to Alzheimer's disease. That has spurred a search for new ways to conduct neuroscience experiments.

One alternative entails growing the largest part of the developing brain in a laboratory dish. These "organoids" most likely will give brain scientists information that cannot be obtained from mouse studies; they are already being used in investigations of the Zika virus.

Grow Your Own

The technology that coaxes stem cells to develop into different types of biological tissue has now been used to grow a part of the brain that contains the cortex and other structures and is responsible for such higher mental functions as processing information from the outside world, forming memories and making decisions. To create such a mini brain, researchers give a tiny ball of cells nutrients and a bed on which to grow; then the cells recapitulate much of the developmental process that occurs in the early embryo.

1 The procedure begins with embryonic stem cells or induced pluripotent stem cells capable of turning into any cell type in the body. The latter cells can be derived from adult skin or blood cells that have been genetically altered.

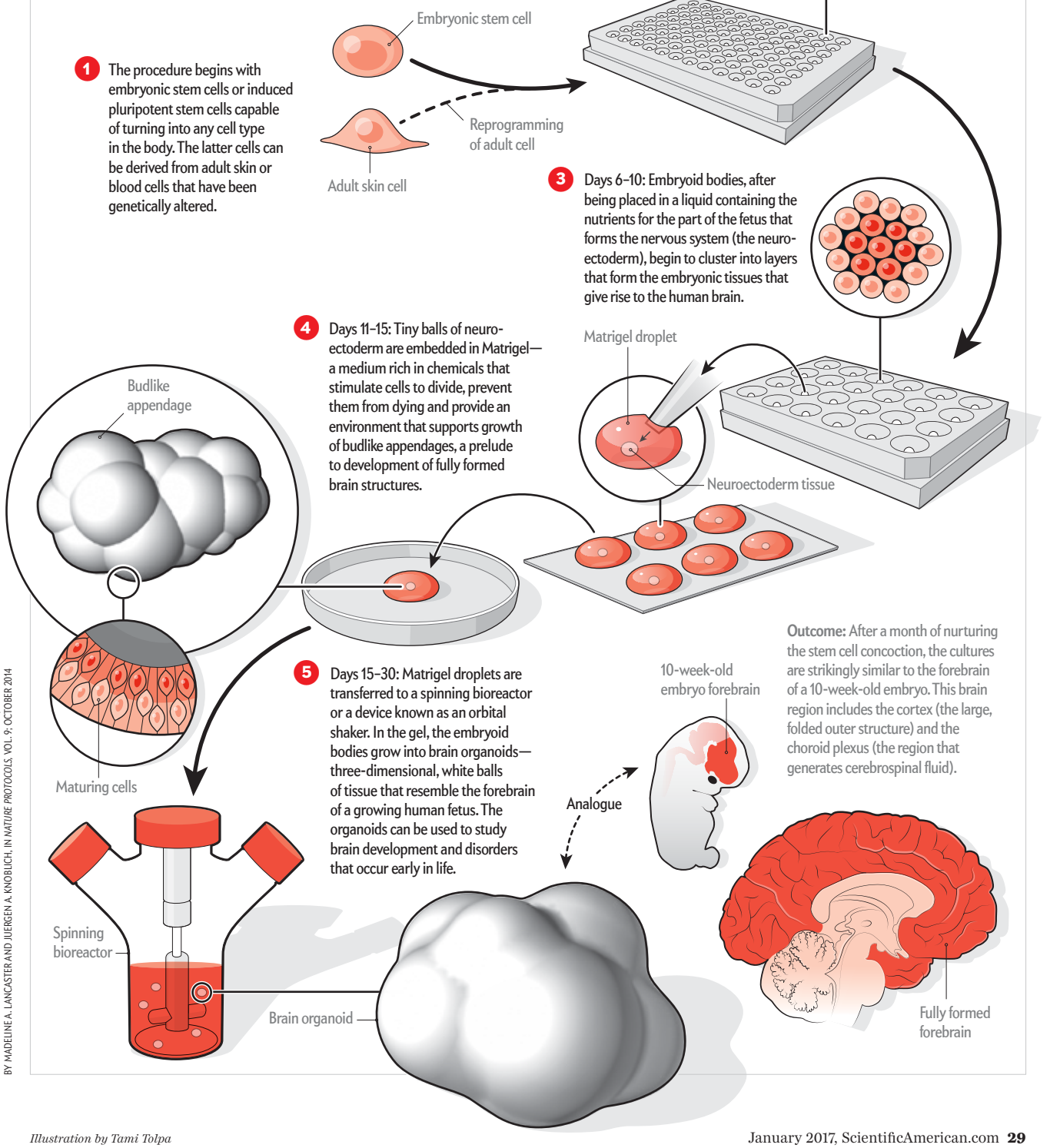
2 Days 0–5: The cells divide and aggregate into balls called embryoid bodies. Within three days, those cells start forming three distinct layers: ectoderm, mesoderm and endoderm.

3 Days 6–10: Embryoid bodies, after being placed in a liquid containing the nutrients for the part of the fetus that forms the nervous system (the neuroectoderm), begin to cluster into layers that form the embryonic tissues that give rise to the human brain.

4 Days 11–15: Tiny balls of neuroectoderm are embedded in Matrigel—a medium rich in chemicals that stimulate cells to divide, prevent them from dying and provide an environment that supports growth of budlike appendages, a prelude to development of fully formed brain structures.

5 Days 15–30: Matrigel droplets are transferred to a spinning bioreactor or a device known as an orbital shaker. In the gel, the embryoid bodies grow into brain organoids—three-dimensional, white balls of tissue that resemble the forebrain of a growing human fetus. The organoids can be used to study brain development and disorders that occur early in life.

Outcome: After a month of nurturing the stem cell concoction, the cultures are strikingly similar to the forebrain of a 10-week-old embryo. This brain region includes the cortex (the large, folded outer structure) and the choroid plexus (the region that generates cerebrospinal fluid).



SOURCE: "GENERATION OF CEREBRAL ORGANOIDS FROM HUMAN PLURIPOTENT STEM CELLS," BY MADELINE A. LANCASTER AND JUERGEN A. KNOBLICH, IN *NATURE PROTOCOLS*, VOL. 9; OCTOBER 2014

Illustration by Tami Tolpa

amazing substance called Matrigel. This gel, produced by cultured cells that were isolated from a mouse cartilage tumor, resembles the membrane on which cells sit in the fetus. Matrigel, which is rich in factors that both stimulate cells to divide and prevent them from dying, provides a scaffold that is stiff enough for cells to grasp but malleable enough to be modified by the cells, which in turn alter its shape.

The outcome of these experiments has been truly spectacular. Left to their own devices in the gel, the embryoid bodies grow into three-dimensional, white balls of tissue that resemble the embryonic human brain. Exposed to the proper chemical signals that trigger fetal brain development, stem cells grow into exact replicas of the human forebrain, the region responsible for higher mental functions. It includes such components as the cortex (the large, folded outer structure) and the choroid plexus (the region that generates cerebrospinal fluid). We also find other structures that guide cells to their proper place in the developing brain. The medial and lateral ganglionic eminences, which perform this function, assist in giving rise to cells that generally tamp down neural activity (interneurons) and the hippocampus, which is involved in memory formation.

Organoids derived from stem cells have already aided research on the Zika epidemic.

Cells in a growing organoid arrange themselves identically to those in the brain of an eight- to 10-week-old human fetus. In rare cases, the organoids even grow small eyecups, indentations in the tissue that contain colored pigments, much as occurs when the human eye begins to form. Also, as happens in a developing brain, the cells divide and give rise to the kinds of nerve cells found in an embryo. And the nerve cells send out axons—long cables that make contact with other neurons to form an active signaling network. Before forming these networks, the neurons migrate from one area to another, much in the way they do in the fetus, potentially providing clues to what happens when neurons end up in the wrong place, as they often do in psychiatric disorders.

ON THE SHOULDERS OF GIANTS

THE IDEA OF BUILDING TISSUES in culture is not really new. As with most scientific discoveries, the current organoid boom relies on years of pathfinding research, some of it dating back more than a century. Already in 1907 zoologist Henry Wilson had demonstrated that certain lower animals, such as sponges, can put themselves back together after being broken up into single cells, an indication that the brain is endowed with a program for assembling its myriad parts.

In 1939 Johannes Holtfreter discovered that the various cells in a frog embryo will seek one another out and regenerate their shape even after they have been completely separated. During the 1980s this finding led to a huge boom in "reaggregation" studies, in which complex animal organs such as the retina and even the cortex were formed in the lab by bringing together their diverse cell types.

Building on early reaggregation experiments conducted from 2006 to 2010, the late Japanese scientist Yoshiki Sasai of the RIKEN Center for Developmental Biology pioneered the use of pluripotent stem cells for growing nervous system tissue, most notably the human retina. In fact, our brain organoid technology merged his techniques with groundbreaking work by Hans Clevers of Utrecht University in the Netherlands, who combined stem cells with Matrigel to establish a culture system that can be used for growing gut, stomach, and even liver and pancreatic tissue.

Beyond drawing lessons from these earlier studies, our work makes use of recently developed technologies that are dramatically turning the entire field of biomedical research upside down. One called reprogramming was developed by Japanese Nobel Prize laureate Shinya Yamanaka of Kyoto University. Through a simple set of genetic manipulations, reprogramming turns body cells that have already fully matured back into pluripotent stem cells—and it can do so for virtually any cell, from skin to blood cells. Stem cells from a sample of skin or blood can then be transformed into various types of brain cells, and those cells can then be grown into organoids. The approach can thereby avoid the need to use cells derived from embryos.

Reprogramming allows an organoid grown from the cells of a patient with a genetic disorder to be compared with ones from a healthy individual to ferret out underlying causes of a disease, because the genetic defect in the patient's cells should afflict the organoid much as it affects the developing fetus. In fact, we have already used the organoid technology to gain insight into microcephaly, in which patients are born with a brain of severely reduced size. We found that organoids grown from cells of a patient with microcephaly are much smaller than normal. Because we can grow the patient's cells in unlimited numbers, we can now undertake detailed analyses of the chain of molecular events that leads to microcephaly in a developing fetus. Much the same should be true for other brain disorders: using patients' cells to grow organoids may enable neuroscientists to better understand the defects in brain formation that underlie schizophrenia, epilepsy and other diseases that are difficult or impossible to study in animals.

Organoids derived from the reprogrammed cells of individuals who are not ill can also be useful. Indeed, they have already been put to good use during the current Zika epidemic, which has been blamed for causing microcephaly in a number of babies born to women infected during pregnancy. Multiple labs working on organoids, first in Brazil and then in the U.S., have now established that the virus can lead to microcephaly—a link that would have remained hypothetical were it not for this new technology. When organoids are infected with the Zika virus, their nerve cells die and the resulting organoids are much smaller than their uninfected counterparts, much like the ones we have grown from our microcephaly patient.

Organoids most likely will help with other Zika research. By growing multiple organoids and infecting each with a separate viral strain from different areas of the world, we can try to understand why the virus causes microcephaly in some regions but not others. We can also use organoids to explore why only some individuals develop microcephaly after Zika exposure. And organoids may be used to identify the docking point, or re-

SCIENTIFIC AMERICAN ONLINE Watch an interview with Knoblich at ScientificAmerican.com/jan2017/mini-brain

ceptor, used by the virus to gain entry to cells—and they may be critical for testing potential anti-Zika drugs before moving them into clinical trials with patients.

A second technique propelling the use of organoids is genome engineering—a collection of methods that allows researchers to alter a cell's genetic code. Organoids engineered to incorporate mutations suspected of causing disease can enable researchers to determine whether the genetic defects actually do lead to illness. Ultimately investigators may be able to evaluate whether repairing those mutations would generate healthy organoids; if so, the work could lead to new treatments that counteract the mutations' effects.

Neuroscientists are eager to explore still other applications of mini-brain technology, such as drug development. The technology can assess whether new medications affect brain tissue in desired ways, obviating the need for animal testing and thus saving on the costs of drug development. The organoids can also let scientists identify unwanted effects on the developing human brain, thereby preventing drugs that would be harmful during gestation from ever reaching a pregnant woman. If the notorious drug thalidomide, which disrupts the developing brain early in pregnancy and causes other birth defects, had been tested in this way, it presumably would not have been prescribed for morning sickness in the late 1950s and 1960s.

Organoids are becoming an invaluable tool for evolutionary biologists. They can be used to identify genes responsible for the enormous size of the human brain compared with other primates. Contrasting human and primate genomes has already identified genes that might be responsible for cognitive functions, such as language, that are unique to humans. Understanding the workings of these genes has remained largely a matter of speculation. Now scientists can introduce genes isolated from monkeys and apes into organoids to determine how they affect brain development. Researchers can also insert genes or entire regions of a genome into a monkey organoid to make them function in a more humanlike manner.

SHOULD WE BE AFRAID?

THE IDEA OF GROWING a human brain in a dish is sure to make some people squeamish. Movies such as *The Matrix* come to mind that evoke fantasies about lab-grown brains developing thoughts or even personalities. These are needless fears. The probability that a lab-grown brain will develop a mind of its own is nil. An organoid is not a "humanoid" in a jar and will not be one even in the far future. Any conscious being needs to be able to process information from the senses to develop an internal mental model of reality. Organoids are neither able to see nor hear and lack any sensory input. Even if we were to connect them to a camera and a microphone, the incoming visual and auditory information would still need to be translated into a form that could be understood by these brain cells in a dish—and, as things stand, providing that translation is an insurmountable technical challenge.

Organoids are not functional brains, only lumps of tissue that imitate the molecular and cellular functioning of the organ at spectacular levels of detail. They are similar to pieces of tissue removed during brain surgery, not conscious beings.

Still, growing an organoid does raise certain ethical and legal issues. All organoids derive from cells taken from individuals who have certain legal rights. As such, performing this work in the lab must conform to the same set of legal and ethical procedures used for samples taken from patients in any industrial country. Patients, of course, must give permission before their cells can be used for research. The same set of rules applies with organoids. But even when the benefits are clearly explained, donors may not at first feel comfortable with the idea of having their cells cultured into brainlike structures.

WHAT NEXT?

THE BENEFITS of this cellular technology outweigh any possible downside. Cerebral organoids have laid the foundation for performing realistic medical and toxicology experiments in human tissue, without the need for animal experiments. Even so, I and others would like to improve them. For instance, the current generation lacks blood vessels. That absence is not a problem during the early stages of organoid development, but over time cells start dying from lack of oxygen and nutrients. In theory, it should be possible to provide blood vessels, either through new 3-D-printing techniques or by growing them from stem cells. Blood vessels are known to grow into the brain, a process that could potentially be recapitulated with a 3-D culture.

In another challenge, we want to make organoids that, in common with an actual brain, have front-to-back, top-to-bottom and left-to-right axes. Unlike a real embryo that has clearly defined body axes, organoids lack a front-to-back and head-to-tail axis. As a result, they develop randomly, so that their individual parts have different orientations. In the developing brain, complex signaling systems give a brain its sense of up versus down—and these same chemicals may ultimately do so for organoids as well. Modern biotechnology methods can generate tissue cultures in which the chemicals needed to spur cell growth during development are present. These techniques may eventually result in the formation of organoids with a forebrain on one end and the hindbrain at the opposite end.

We have already begun to push forward to begin to look for ways to overcome these barriers. We have demonstrated technical feats that we could only dream of a few years ago. Organoids are already helping to achieve a better understanding of disease and are assisting in developing drug candidates. The ability to grow parts of a brain and work with the living sample has begun to open an entirely new chapter in biological research by providing vastly more realistic lab cultures—and at times even a reasonable alternative to using animals in doing research. SA

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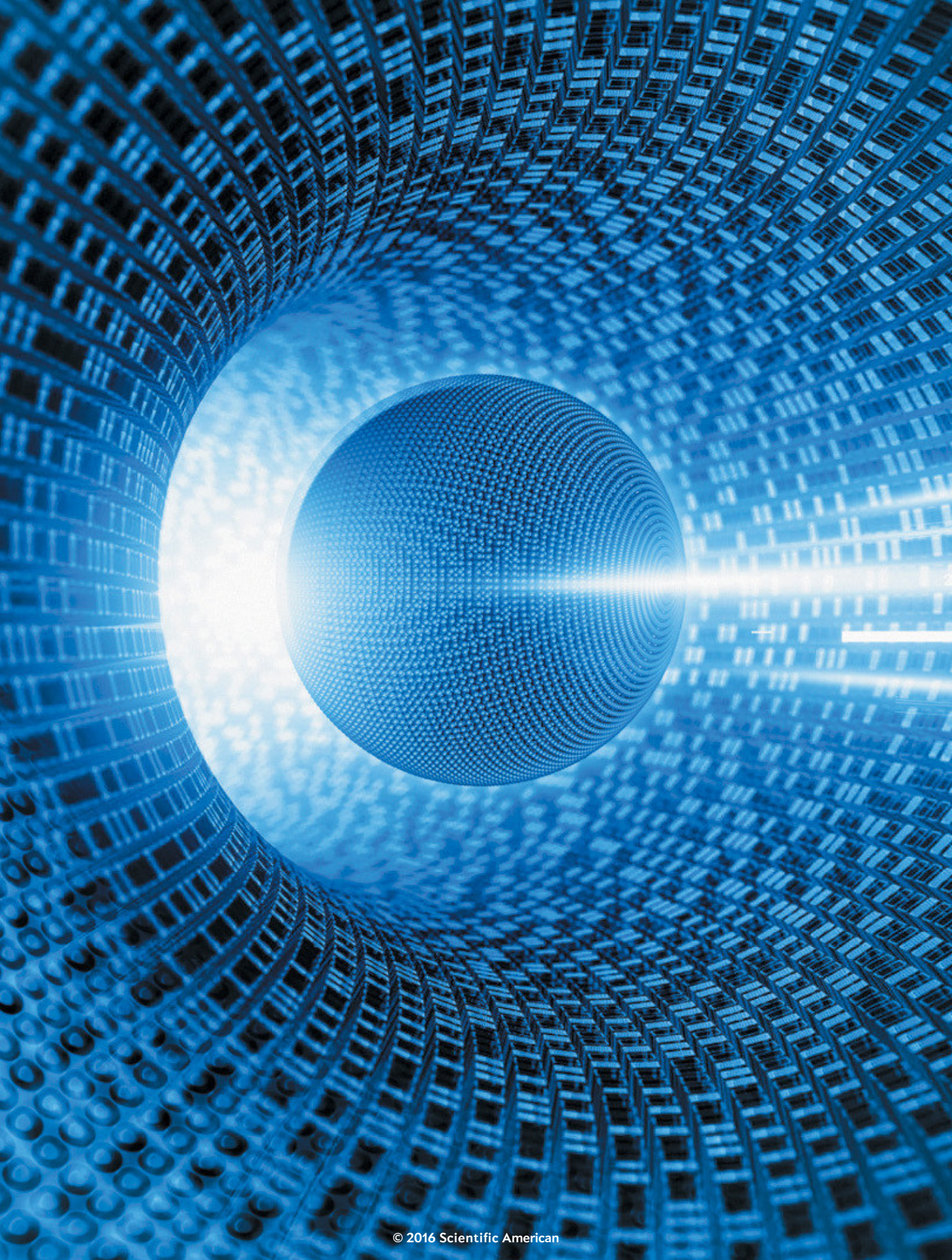


SPACE

Tangled Up in Spacetime

The collaborative project "It from Qubit" is investigating whether space and time sprang from the quantum entanglement of tiny bits of information *By Clara Moskowitz*

Illustration by Kenn Brown, Mondolithic Studios

Clara Moskowitz is *Scientific American*'s senior editor covering space and physics. She has a bachelor's degree in astronomy and physics from Wesleyan University and a graduate degree in science journalism from the University of California, Santa Cruz.

"ALL THE WORLD'S A STAGE," SHAKESPEARE WROTE, AND PHYSICISTS TEND TO THINK that way, too. Their stage happens to be space itself, and to them, space sometimes seems like a mere backdrop to the action of the forces and fields that inhabit it. Space, the conventional thinking goes, is not made up of anything at all.

Scientists have begun to question this convention, however. Space—or rather, in the language of general relativity, spacetime—may actually be composed of tiny chunks of information. These chunks, this thinking goes, interact with one another to create spacetime and give rise to its properties, such as the curvature that causes gravity. This notion, if correct, would not just explain spacetime. It could also help physicists achieve a long-sought quantum theory of gravity, which would merge general relativity and quantum mechanics, the two grand theories of the universe that tend not to get along. The excitement of such a possibility has lately engrossed hundreds of physicists who meet every three months or so under the auspices of a project dubbed "It from Qubit."

The "it" in this case is spacetime, and the qubit (pronounced "cue-bit," from "quantum bit") represents the smallest possible amount of information—akin to a computer "bit" but on a quantum scale. The animating idea behind It from Qubit is the notion that the universe is built up from some underlying code and that by cracking this code, physicists will have finally found a way to understand the quantum nature of large-scale events in the cosmos. A recent It from Qubit (IfQ) meeting was held in July 2016 at the Perimeter Institute for Theoretical Physics in Ontario. Organizers were expecting about 90 registrants but got so many applications they wound up taking 200 and simultaneously running six remote satellite sessions at other universities. "I think this is one of the most, if not *the* most, promising avenues of research toward pursuing quantum gravity," says Netta Engelhardt, a postdoctoral researcher at Princeton University who is not officially involved in It from Qubit but who has attended some of its meetings. "It's just taking off."

Because the project involves both the science of quantum computers and the study of spacetime and general relativity, it brings together two groups of researchers who do not usually collaborate—quantum information scientists on one hand and high-energy physicists and string theorists on the other. More than a year ago the Simons Foundation, a private organization that supports science and mathematics research, awarded a grant to found the It from Qubit collaboration and finance physicists to study and hold meetings on the subject. Since then, excitement has grown, and successive meetings have drawn in more and more researchers, some official members of the collaboration funded by Simons and many others simply interested in the topic. "This project is addressing very important questions but very difficult questions," says IfQ collaborator Beni Yoshida, a postdoctoral researcher at Perimeter. "Collaboration is necessary—it's not like a single person can solve this problem."

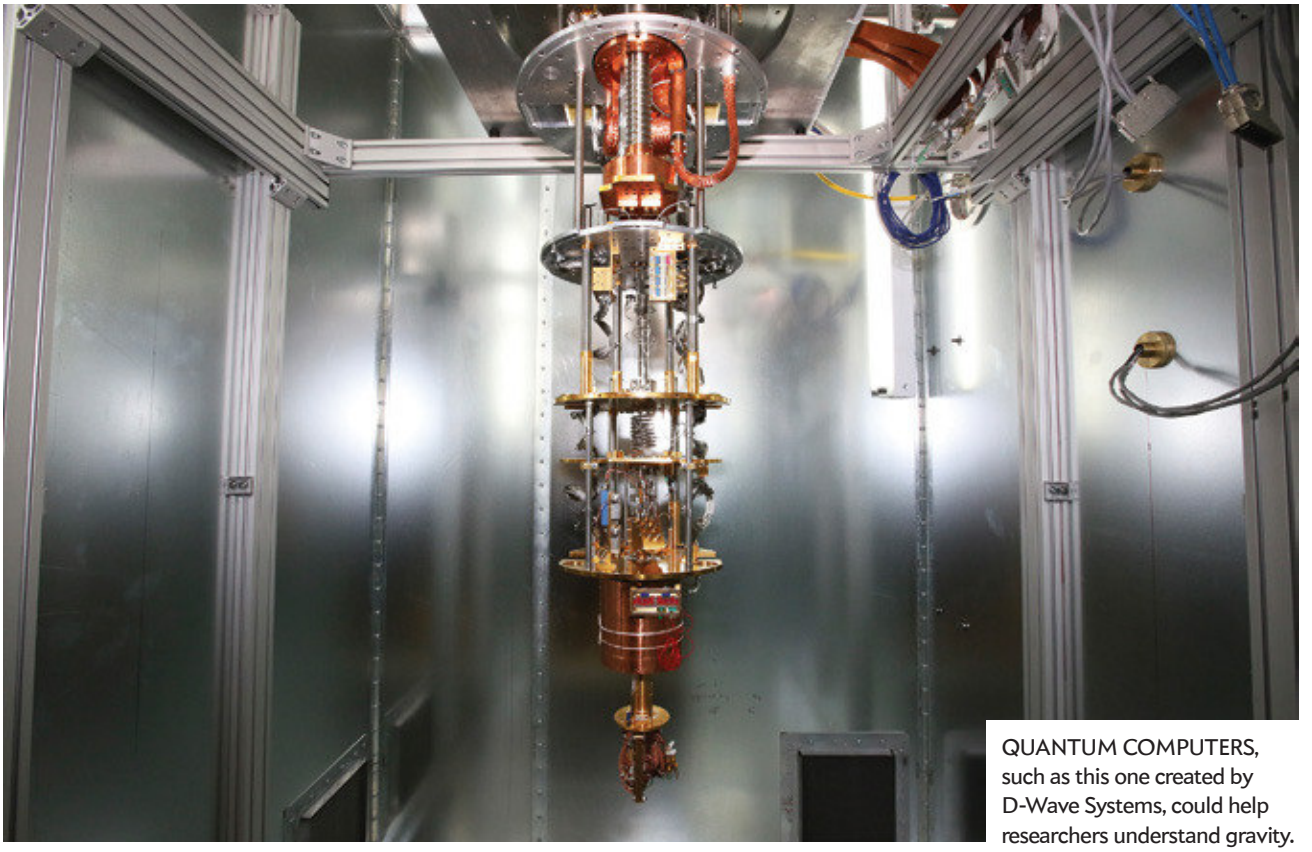
Even scientists not working on IfQ have taken notice. "If the link with quantum information theory proves as successful as some anticipate, it could very well spark the next revolution in our understanding of space and time," says string theorist Brian Greene of Columbia University, who is not involved in IfQ. "That's a big deal and hugely exciting."

ENTANGLING SPACETIME

THE NOTION THAT SPACETIME has bits or is "made up" of anything is a departure from the traditional picture according to general relativity. The new view holds that spacetime, rather than being fun-

IN BRIEF

Could spacetime be made of tiny building blocks of information? If so, the building blocks might be bound together by the bizarre phenomenon of quantum entanglement, in which two particles separated by great distances can retain an instantaneous connection. **Scientists are pursuing** this idea through a new research program called It from Qubit, which unites scientists from quantum computing with physicists who study general relativity and string theory. **Eventually the researchers aim** to find a quantum theory of gravity that can merge the incompatible theories of quantum mechanics and general relativity.



QUANTUM COMPUTERS, such as this one created by D-Wave Systems, could help researchers understand gravity.

damental, might "emerge" via the interactions of qubits. What, exactly, are these bits made of, and what kind of information do they contain? Scientists do not know. Yet intriguingly, that does not seem to bother them. "What matters are the relationships" between the bits more than the bits themselves, says IfQ collaborator Brian Swingle, a postdoc at Stanford University. "These collective relationships are the source of the richness. Here the crucial thing is not the constituents but the way they organize together."

The key to this organization may be the strange phenomenon known as quantum entanglement—a weird kind of correlation that can exist between particles, wherein actions performed on one particle can affect the other even when a great distance separates them. "Lately one absolutely fascinating proposal is that the fabric of spacetime is knitted together by the quantum entanglement of whatever the underlying 'atoms' of spacetime are," says Vijay Balasubramanian, a physicist at the University of Pennsylvania who is an IfQ principal investigator. "That's amazing if true."

The reasoning behind the idea comes from several earlier discoveries by physicists, such as a 2006 paper by Shinsei Ryu, now at the University of Illinois at Urbana-Champaign, and Tadashi Takayanagi, now at Kyoto University in Japan, showing a connection between entanglement and the geometry of spacetime. Building on that work, in 2013 physicist Juan Maldacena of the Institute for Advanced Study in Princeton, N.J., and Stanford physicist Leonard Susskind found that if two black holes became entangled, they would create a wormhole—a shortcut in spacetime predicted by general relativity. This discovery (nicknamed ER=EPR, after physicists' shorthand for wormholes and entanglement, based on the names of the scientists who suggested them) and others like it suggest, surprisingly, that entanglement—which was thought to involve no physical link—can produce structures in spacetime.

To understand how entanglement might give rise to spacetime, physicists first must better understand how entanglement works. The phenomenon has seemed "spooky," in the words of Albert Einstein, ever since he and collaborators predicted it in 1935, because it involves an instantaneous connection between particles at great distances that seems to defy the limitation that nothing can travel faster than the speed of light. Lately scientists have been studying several different kinds of entanglement. Conventional entanglement involves linking a single characteristic (such as a particle's spin) in multiple particles of the same type spread out in space. But "conventional entanglement is not enough," Balasubramanian says. "I've come to realize that there are other forms of entanglement that turn out to be relevant for this project of reconstructing spacetime." One could, for instance, entangle particles of a certain kind at one location with particles of a different kind at the same location—an entanglement that does not involve space. Scientists are also tackling the confusing complexities of entangling larger numbers of particles.

Once the dynamics of entanglement are clearer, scientists hope to comprehend how spacetime emerges, just as the microscopic movements of molecules in the air give rise to the complex patterns of thermodynamics and weather. These are emergent phenomena, Engelhardt says. "When you zoom out of something, you see a different picture that you wouldn't know comes about because of smaller dynamics. This is one of the most fascinating things about It from Qubit because we don't understand the fundamental quantum dynamics from which spacetime emerges."

KIM STALLKNECHT *Redux Pictures*

COSMIC HOLOGRAMS

THE MAJOR GOAL of all this work is to finally achieve a theory that describes gravity from a quantum perspective. Yet physicists chasing this goal have been stymied for the past century—Einstein himself pursued such a theory doggedly until his death, with no success. The It from Qubit scientists are banking on an idea known as the holographic principle to help them.

This principle suggests that some physical theories are equivalent to simpler theories that work in a lower-dimensional universe, in the same way that a 2-D postcard with a hologram of a unicorn on it can contain all the information necessary to describe and portray the 3-D shape of the unicorn. Because finding a working theory of quantum gravity is so hard, this thinking goes, physicists could aim to discover an equivalent, easier-to-work-with theory that operates in a universe with fewer dimensions than ours.

One of the most successful embodiments of the holographic principle is a discovery known as the AdS/CFT correspondence

Perhaps what we think of as gravity and spacetime is just another way of looking at the end product of entanglement.

(an acronym for the technical term "anti–de Sitter/conformal field theory correspondence"), which shows one can completely describe a black hole by describing what happens on its surface. In other words, the physics of the inside—the 3-D "bulk"—corresponds perfectly to the physics of the outside—the 2-D "boundary." Maldacena found this relation in the late 1990s, working within the framework of string theory, which is yet another attempt at a theory of quantum gravity. String theory replaces all the fundamental particles of nature with tiny, vibrating strings.

AdS/CFT might allow physicists to discover a theory that is equivalent to quantum gravity, accomplishes all the same goals and can describe all the same physics but is much easier to work with—by leaving out gravity altogether. "Theories with gravity are very difficult to get quantum descriptions of, whereas theories that don't have gravity are much easier to describe completely," Balasubramanian says. But how, one might ask, could a theory that leaves out gravity ever be a theory of so-called quantum gravity? Perhaps what we think of as gravity and spacetime is just another way of looking at the end product of entanglement—in other words, entanglement might somehow encode the information from the 3-D bulk into bits stored on the 2-D boundary. "It's a very exciting direction," he says.

For about 20 years scientists have found that the AdS/CFT correspondence works—a 2-D theory can describe a 3-D situation, a setup known as a duality—but they do not fully understand why. "We know these two theories are dual, but it's not exactly clear what makes the duality work," Swingle says. "One output [of IfQ] you could hope for is a theory for how these dualities arise. That's something I think definitely can and will happen as a result of this collaboration, or at least [we will make] major progress toward that."

Quantum information theory may be able to help because a concept from this field called quantum error–correcting codes could also be at work in the AdS/CFT correspondence. Scientists researching quantum computing devised these codes to help protect information from being lost if anything interferes with the entanglement between bits. Quantum computers, rather than encoding information in single bits, use highly entangled states of multiple bits. That way a single error cannot affect the accuracy of any piece of information. Strangely, though, the same mathematics involved in quantum error–correcting codes shows up in the AdS/CFT correspondence. It seems that the arrangement scientists use to entangle multiple bits together into error-proof networks could also be responsible for encoding the information from the interior of the black hole onto its surface through entanglement. "It's very intriguing that you find quantum error–correcting codes inside black holes," says quantum information scientist Dorit Aharonov, an IfQ principal investigator at the Hebrew University of Jerusalem. "Why on earth would that happen? These connections are just fascinating."

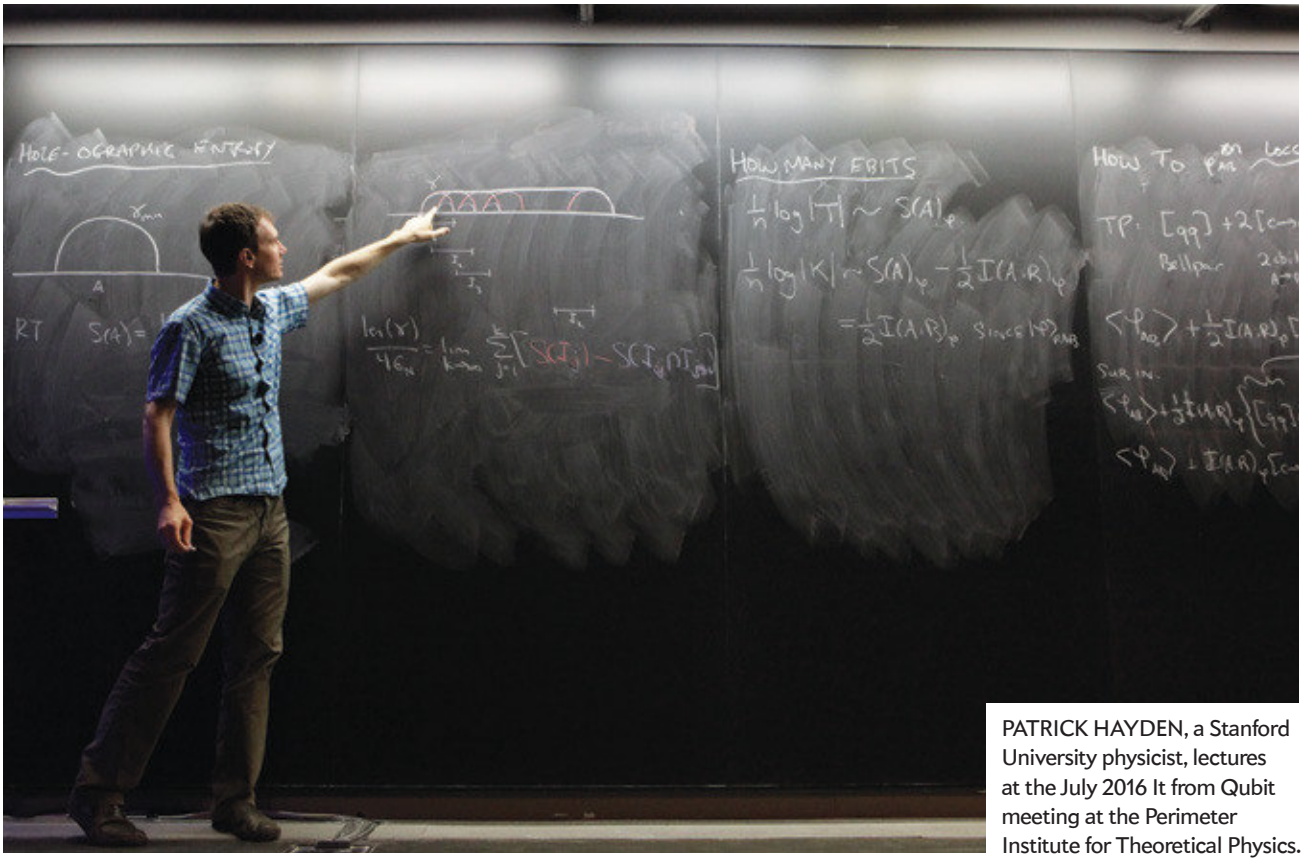
Even if physicists manage to understand how the AdS/CFT correspondence works and thereby devise a lower-dimensional theory that stands in for quantum gravity, they are still not home free. The correspondence itself works only in a "toy model" of the universe that is somewhat simplified from the fully realized cosmos we inhabit. In particular, all the rules of gravity that apply in our real universe are not in play in the streamlined world of the correspondence. "AdS/CFT has a kind of gravity, but it's not the theory of gravity in an expanding universe like the one we live in," Swingle says. "It describes a universe as if it was in a bottle—if you shine a light beam, it bounces off the walls of the space. That doesn't happen in our expanding universe." This model gives physicists a useful theoretical playground in which to test their ideas, where the simplified picture makes tackling quantum gravity easier. "You can hope it's a useful way station in the eventual goal of understanding gravity in our own universe," Swingle says.

If IfQ is based on an unrealistic foundation, some skeptics say, how productive can it ever be? "That certainly is one very valid criticism," Engelhardt says. "Why are we focusing on this toy model? All of this depends on the validity of the toy model and the idea that in the end the toy model is representative of our universe. I would like to make sure that if we understand the toy model, we understand the real deal." IfQ researchers are betting that by starting with a simplified picture that is easier to work with, they can eventually add the necessary complexity to apply the theory to the real world.

THE PAYOFF

DESPITE THEIR DOUBTS, scientists inside and outside the project say the approach is worth trying. It has already turned up new avenues of research to pursue. "I've long felt that the relation between quantum information and quantum gravity is of fundamental importance," says Raphael Bousso, a physicist at the University of California, Berkeley, who is not involved in IfQ but has

SCIENTIFIC AMERICAN ONLINE Watch a video about quantum entanglement at ScientificAmerican.com/jan2017/entanglement



PATRICK HAYDEN, a Stanford University physicist, lectures at the July 2016 It from Qubit meeting at the Perimeter Institute for Theoretical Physics.

COURTESY OF JONGBUM PARK *Perimeter Institute for Theoretical Physics*

worked with some of its collaborators. "The connection has deepened over the years, and I'm thrilled that so many outstanding scientists are now working together to confront these questions and see where they lead us." Stanford theorist Eva Silverstein, who is not part of the collaboration, concurs: "It is clearly worthwhile to develop and apply quantum information to these problems. But to understand the dynamics [of quantum gravity], much more is required, and it is important for the field not to focus too narrowly on a single approach."

Furthermore, even if the project does not pay off with a theory of quantum gravity, it is still likely to have beneficial offshoots. Bringing the techniques and ideas of string theory and general relativity to bear on questions of quantum information can, for instance, help to better define the different types of entanglement, both for understanding spacetime and for constructing quantum computers. "When you start playing with these tools in a new setting, it's very likely that it will bring up ideas that are interesting and might be useful in other areas," Aharonov says. "It looks like people are making progress on questions that have been out there for many, many years, so it's exciting." Scientists, for instance, have found that measuring time within wormholes may be possible by thinking of the wormhole as a quantum circuit.

Furthermore, combining quantum information science with string theory may help not just in deriving a theory of quantum gravity but also in evaluating whatever theory the researchers may find. Any physical theory can be thought of as a computer, its input and output akin to the theory's initial state and a later state that can be measured—and some computers are more powerful than others. Once researchers have deduced a quantum gravity theory, they could ask, what is the theory's computational power? "If that power is too large, if our quantum gravity model would be able to compute things that we don't believe can be computed in our world, that would at least raise a question mark on the theory," Aharonov says. "It's a way to actually tell whether the theory is sensible or not from a different point of view."

The project reminds some physicists of the heady days in the past when other big ideas were just getting started. "I became a grad student in 1984, when the so-called first string theory revolution took place," says Hirosi Ooguri, a physicist at the California Institute of Technology. "That was a very exciting time, when string theory emerged as a leading candidate for a unified theory of all the forces in nature. I do see the current explosion of excitement around this similarly. This is clearly an exciting time for young people in the field as well as those of us who received our Ph.D.s decades ago." SA

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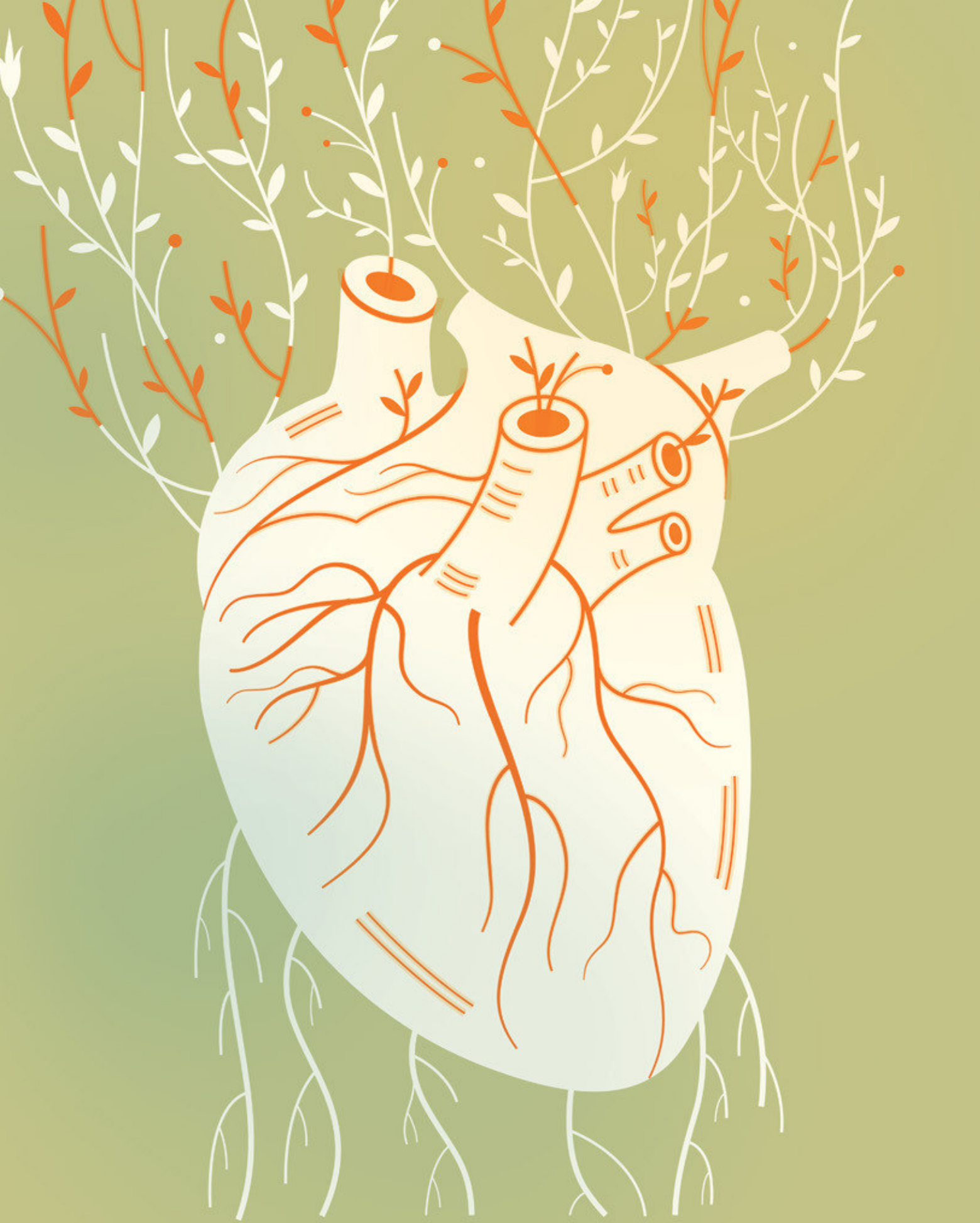

CARDIOLOGY

heart therapy

Harnessing the organ's own healing properties may help prevent heart attacks and lessen the painful effects of severely narrowed coronary arteries

By Gabor Rubanyi

Illustration by Harry Campbell

Gabor Rubanyi is a physician and co-founder of Angionetics, a company that is developing a gene therapy to grow new blood vessels in the heart.

THE HUMAN HEART BEATS MORE THAN 100,000 TIMES EVERY DAY, PUMPING ALMOST 2,000 gallons of oxygen-rich blood through the aorta to the rest of the body. About 5 percent of that flow finds its way to two major vessels—the coronary arteries—which channel it to a network of progressively smaller blood vessels that feed each fiber of the cardiac muscle.

If something—such as a blood clot or a thick buildup of fatty material (atherosclerotic plaque) in the walls of the arteries—interrupts the circulation at one or more points in the coronary vessels, the blockage robs nearby cardiac cells of oxygen and nutrients. Unless the flow of blood resumes quickly, the starved part of the heart muscle dies: the person has a heart attack. Depending on how far the damage spreads, the heart may have trouble functioning properly or may even stop working altogether, leading to death.

Because cardiac muscle cells do not die immediately in response to a lack of oxygen, many of them can be preserved if a patient gets to the hospital quickly enough to allow doctors to act before permanent damage occurs. Among other things, physicians may prop open narrowed arteries with stents or surgically bypass the blocked section of an artery. These procedures are also used to try to prevent heart attacks from happening in the first place as well as to lessen the pain (angina) that often accompanies a severe narrowing of the arteries, but they do not always work and sometimes bring about new problems.

As it happens, the heart has its own way of dealing with blockages in the coronary arteries. It can develop new channels—called collateral vessels—that redirect blood flow from several new directions to oxygen-starved areas of the cardiac muscle. Collateral vessels are present from birth, but they do not usually carry blood. They grow larger and may also form anew after severe blockage or narrowing of coronary arteries takes place and then only after several weeks. In a person with a well-developed collateral system, the extra flow may be enough to keep heart tissue nourished even in the face of a fully closed vessel. But too often the natural collateral circulation is not up to the task.

A number of researchers—myself included—have spent the past two decades experimenting with ways to spur the heart to produce new collateral vessels that are able to provide adequate blood flow in the hearts of patients whose muscle fibers are not getting enough oxygen. By doing so, we hope to reduce the pain felt by many patients with advanced atherosclerosis as well as to avoid heart attacks in patients who can no longer be helped by stents or bypass surgery. So far our efforts—which have included injecting various proteins, genes and cells into the heart—have not yet yielded a remedy that works well enough for the majority of people whose arteries have become dangerously narrowed. Over the past few years, however, some of us in industry and at universities have refined our procedures dramatically. A number of these approaches are now being combined in human trials that should be completed in the not too distant future.

If we are successful, the first people to notice the difference will probably be those who suffer from angina, which manifests during stress or physical activity when coronary arteries damaged by atherosclerosis can no longer provide all the oxygen

IN BRIEF

The heart has the ability to grow extra blood vessels when under duress. This so-called collateral circulation can mean the difference between life and death after a heart attack by creating new channels to bring blood to damaged parts of the heart muscle. **For reasons** that are not completely clear, however, most cardiac patients are unable to develop a good collateral network.

Researchers are testing genetic and cellular therapies to promote new blood vessel growth in the heart. If successful, the treatments could help many avoid chest pain or prevent heart attacks.

New Pathways for a Struggling Heart

The heart sometimes has the ability to grow new arteries. Researchers are testing gene therapies to try to boost this regenerative capacity to restore oxygen-rich blood flow to a region of the cardiac muscle where normal circulation has dropped off because of a fatty buildup (atherosclerotic plaque) inside one or more major blood vessels. If successful, these treatments may one day be used, among other things, to lessen the chest pain that often occurs when part of the heart cannot get enough oxygen (a condition called ischemia).

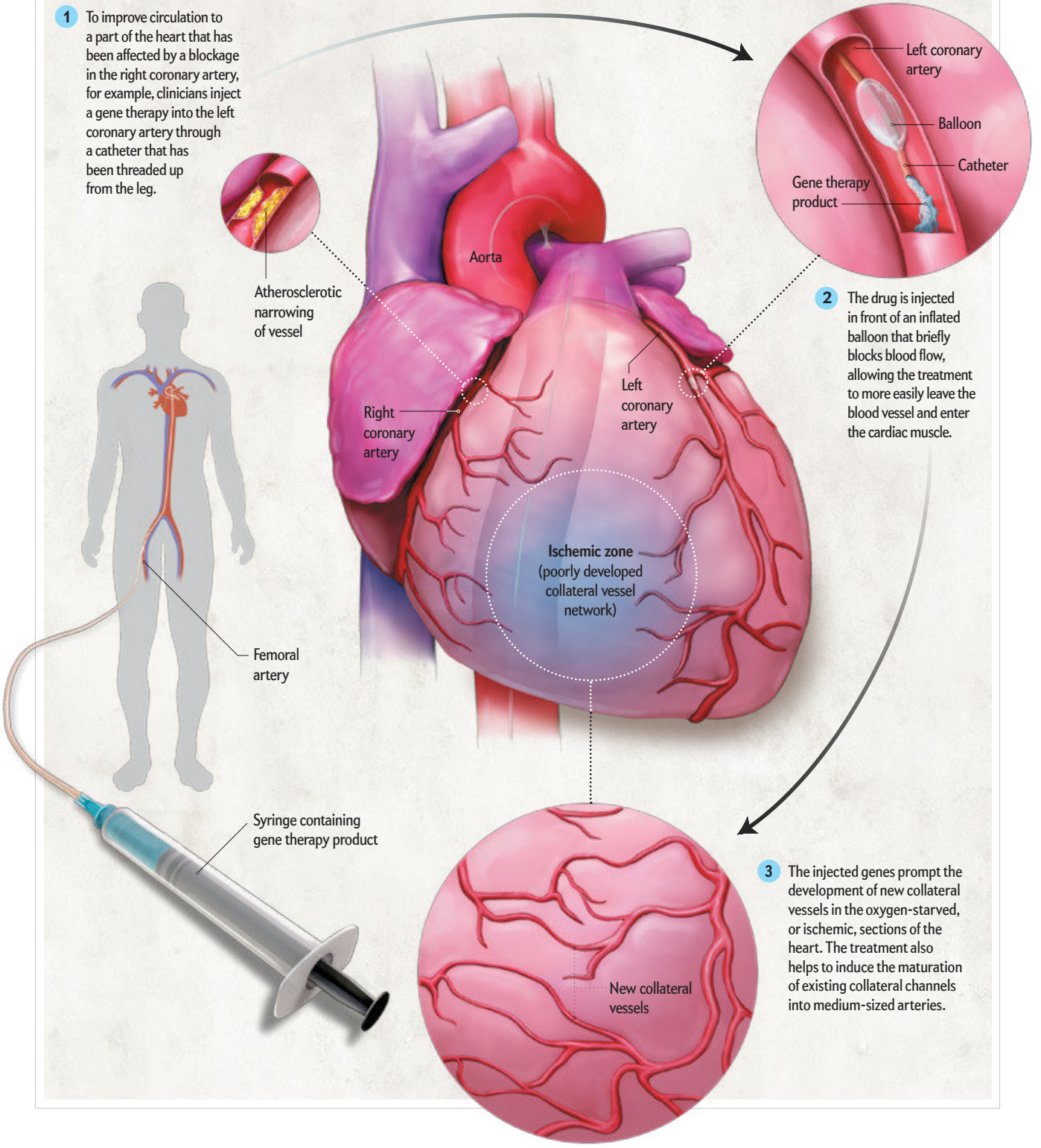

Illustration by Mesa Schumacher

needed by the cardiac tissue. For a variety of reasons, standard treatments with medication, stents or surgery cannot help several million angina patients around the world—an estimated 850,000 of whom live in the U.S. A brand-new therapy that relieved their symptoms would dramatically improve their quality of life, allowing many, for example, to walk around the neighborhood instead of being confined indoors. It should also aid at least some fraction of them to avoid having a first or a repeat heart attack.

COLLATERAL FORMATION

THE FIRST STEP toward devising a treatment for spurring the growth and development of new blood vessels in the heart is to figure out why collateral vessels sometimes appear and mature on their own. For years investigators have debated which of two different forces prompts existing collateral channels to turn themselves into medium-sized arteries: Increased blood flow in the collateral channels or decreased oxygen in ailing cardiac muscle? These conditions may ensue whenever the inside of a coronary artery becomes severely narrowed. The pressure inside the artery beyond the choke point decreases because less blood can get through the smaller space. This decrease causes an imbalance that starts the flow of blood into the "downstream" collaterals from other unaffected areas of the heart. At the same time, the cardiac tissue beyond the narrowed passage of the artery receives less oxygen because less blood is getting through. Some studies found more evidence for the blood flow explanation; others pointed to lower oxygen levels.

It now looks as though both processes play an important role in the development of collateral circulation in the human heart. The new blood flow into ancillary channels creates shear forces that cause the inner lining to release proteins called growth factors that in turn prompt the walls to become stronger and the inner diameter to grow. Subsequently, the newly maturing arteries can handle an increased flow of blood. Meanwhile the lack of oxygen in the heart muscle stimulates the release of other growth factors that trigger the formation of new collateral channels, which can become small arteries.

Over the past 15 years investigators have found that just 20 to 30 percent of cardiac patients have a well-developed collateral circulation. No one is quite sure why, but the collateral network in most people with coronary artery disease does not develop enough to get around the blockages in their coronary arteries. Some studies suggest that high blood cholesterol levels and the damage to small blood vessels caused by diabetes, in particular, may interfere with collateral vessels' ability to change.

Having useful collateral vessels in the heart can, however, mean the difference between life and death. In a study of 845 people with serious heart disease published online in 2013, Christian Seiler of University Hospital of Bern in Switzerland and his colleagues showed that those patients whose collateral blood supply could replace at least 25 percent of their once normal coronary blood flow were 67 percent less likely to die from their heart problems over the course of 10 years.

RESEARCH CHALLENGES

OVER THE PAST FEW YEARS research has revealed just one proved method for boosting collateral circulation in the heart: exercise that pushes the organ to perform at a higher level than normal for an extended period. A German study of 60 men with serious coronary artery disease published in 2016 demonstrated that 10 hours of high-intensity or 15 hours of moderate-intensity exercise each week for a month increased the amount of blood that could flow through the men's collateral network by about 40 percent. The moderate group exercised six to eight times a day at 60 percent capacity—with 100 percent being the most effort they could expend without triggering chest pain. The high-intensity group exercised four times a day at 95 percent capacity (a level at which people sometimes felt chest pain)—all under the supervision of experienced physicians and personal trainers. The 40 percent improvement is probably about at the theoretical maximum of what is physiologically possible, based on laboratory studies with dogs, which showed that the collateral network can replace about a third of normal circulation through the coronary arteries.

A brand-new therapy that relieves symptoms of angina (chest pain) would dramatically improve the quality of life of many patients, allowing them, for example, to walk around the neighborhood instead of being confined indoors.

Presumably the greater physical activity increased the pressure in study participants' coronary arteries, which in turn forced the blood into the collateral vessels. The regular daily workouts then stimulated the walls to widen and thicken to handle more blood. Whether exercise also triggered the growth of new collateral vessels is unclear because such vessels, even if they had formed, would have been too small at first to show up on an angiogram, a type of x-ray scan used to visualize coronary arteries.

Even moderate exercise is not an option, however, for many people with advanced heart disease—hence the search for the right combination of designer proteins, genes or cells to push the heart to expand its collateral network.

SCIENTIFIC AMERICAN ONLINE Find out more about how researchers hope to coax the heart into repairing itself at ScientificAmerican.com/jan2017/heart

Some of the earliest efforts focused on two different proteins—known by their acronyms VEGF and FGF—that stimulate the growth of blood vessels. Whereas several initial, small studies with these and other growth factors seemed promising, follow-up studies with a larger number of patients revealed numerous issues. Perhaps the biggest problem was that clinicians had to deliver high amounts of proteins over a long period to get any new blood vessels to form in the heart. Meanwhile other parts of the circulatory system elsewhere in the body reacted badly, causing blood pressure to fall—sometimes severely—and the experimental treatments had to be stopped.

A few researchers turned to gene therapy as a way of getting around some of the problems caused by the use of proteins. The idea is to inject genes that contain the molecular instructions for creating VEGF, FGF or other proteins directly in the heart, usually by placing the genes into a relatively benign virus that infects cardiac cells. Once implanted successfully, the genes can churn out the necessary growth factors for an extended period right where they are needed. Although scientists have in fact induced the appearance and maturation of collateral blood vessels in the hearts of lab animals, no large-scale clinical trials of gene therapy for human hearts have so far demonstrated significant benefit—perhaps because the injected genes did not reach enough cardiac muscle cells. Full disclosure: my company, Angionetics, is trying to develop one of these remedies, based on the gene for FGF. Our studies have identified what may be a more effective method of delivering the genetic material to a broader area of the heart, which is essential to form enough new collateral vessels. The U.S. Food and Drug Administration gave us permission in September 2016 to begin advanced testing of our product in 320 people.

Finally, some investigators have tried using so-called adult stem cells, taken from a patient's own bone marrow or blood, to try to entice an ailing heart to develop extra blood vessels. The rationale is that these stem cells can produce a variety of growth factors, and it may well take multiple growth factors—in carefully calibrated combinations—to generate the appropriate number of collateral blood vessels. One of the complicating issues is that it is not always easy to identify how many of the injected cells remain functional in the heart. Nevertheless, several small clinical trials over the past 10 years have resulted in some encouraging findings—such as allowing treated patients to exercise a few minutes longer than untreated patients on a treadmill without pain. But as with the protein and gene therapy techniques, no substantive benefit has so far been documented in large-scale clinical trials of cell therapy.

LESSONS LEARNED

TWENTY YEARS may seem like a long time to spend trying to figure out how to grow collateral blood vessels in the heart without finding a broadly effective solution or giving up. But everything my colleagues and I in the field have learned so far confirms our sense that boosting collateral growth is achievable and could help many people. What we need to do now is pull together the many insights that we have gleaned from the research so far and start applying them more systematically to each new endeavor we undertake.

For example, we have a better understanding today of how any potential treatment should be delivered to the heart to provide the maximum response. Historically, researchers have injected their favored experimental therapy in one of three ways: directly into the cardiac muscle, from which it spreads in a small area between the fibers; through a vein in the heart, pushing it backward against the blood flow; or through a coronary artery, which carries it in the same direction as the flow of blood. Several studies have now shown that the only way to reach the existing collateral channels while stimulating the formation of new collateral networks is to inject experimental drugs into one or more of the coronary arteries. Existing coronary collateral channels are just too far from the injection sites in either the cardiac muscle or veins to benefit from the treatment. We have also learned that temporarily blocking circulation by inflating a tiny balloon inside the artery at the same time that we deliver the drugs makes the vessel walls more permeable, allowing a larger dose to reach the heart.

In addition, one of the most challenging obstacles to demonstrating that a treatment can generate useful collateral vessels in humans is making sure that we are treating the right patients in clinical trials. In all likelihood, remedies to expand existing collateral vessels and grow new ones are not going to do anything for the 20 to 30 percent of cardiac patients whose collateral circulation is already well developed. If such people take part in our experimental studies, their lack of improvement could obscure gains for others; averaging their results with everyone else's would artificially depress the findings, making it seem as though the treatment has failed.

To date, the most accurate method for measuring a person's collateral circulation involves inserting a small balloon through a catheter into a coronary artery, inflating the balloon to block circulation briefly and then measuring how much blood still manages to flow around the obstruction, presumably through the collateral vessels. Realistically, such a procedure is too complex and expensive to identify the majority of patients who could benefit from the production of extra blood vessels in their heart and to verify whether treatment has helped them. Less invasive techniques to estimate collateral circulation have been developed but are not yet as accurate as they need to be. We have to come up with a simple, standard way of measuring collateral flow so that we can identify good candidates for the approach and recognize success when we achieve it.

Taking these and other hard-won lessons into account, I believe we are well on our way to developing new treatments to boost the growth of collateral arteries in the heart. Within the next several years we should finally be able to offer a successful alternative to hundreds of thousands of cardiac patients who currently have no other options. SA

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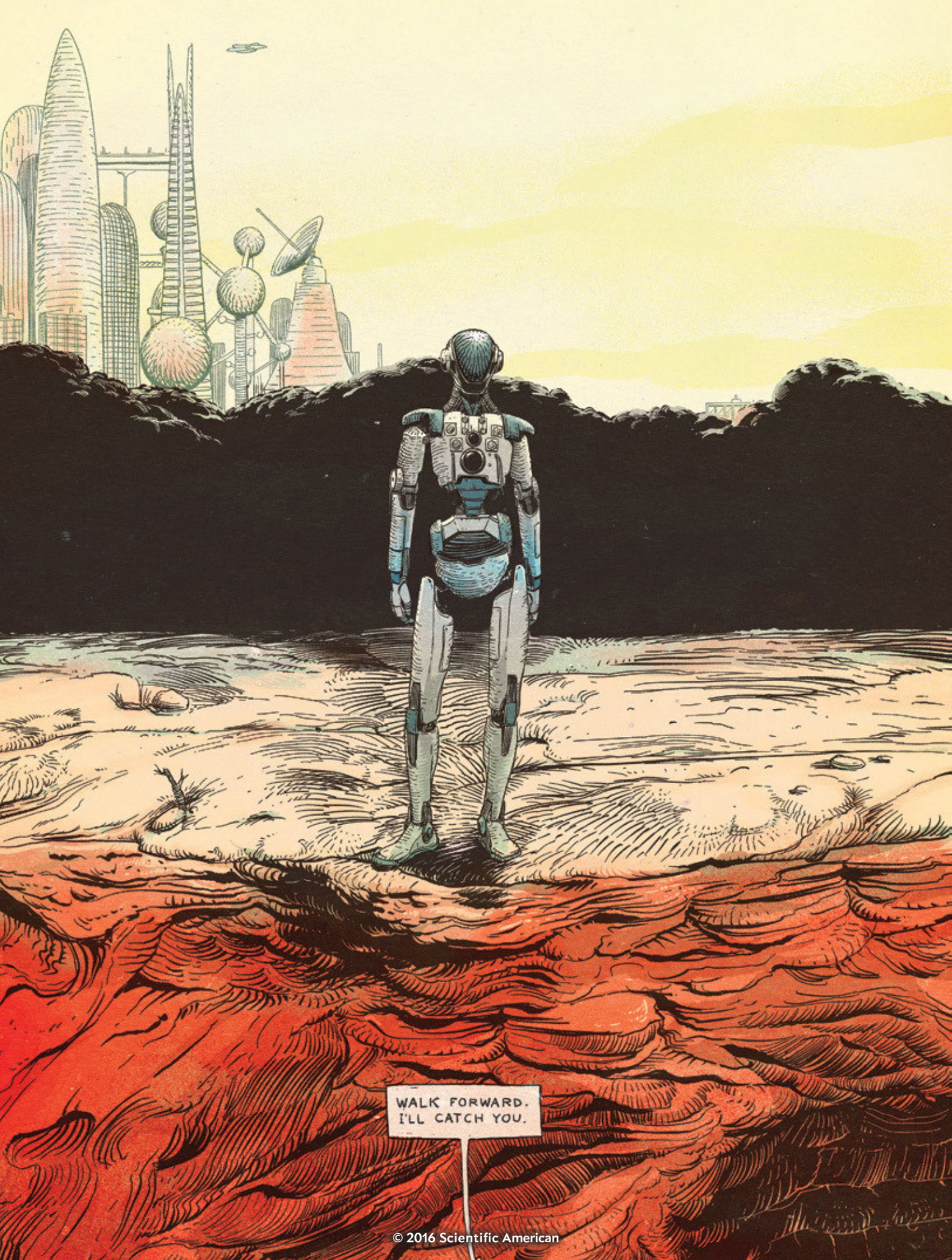

COMPUTING

THE CASE FOR Robot Disobedience

DON'T WORRY ABOUT DEFIANT MACHINES. DEVIOUS HUMAN MASTERS AND MISUNDERSTOOD COMMANDS ARE A BIGGER THREAT

By Gordon Briggs and Matthias Scheutz

IN BRIEF

Human fallibility poses greater immediate risks and challenges than artificial superintelligence as smart machines become increasingly autonomous and ubiquitous.

Robotics researchers have begun to teach machines with rudimentary language and AI capabilities when and how to say "no" to humans.

So-called felicity conditions incorporated in a robot's reasoning mechanisms will help it determine whether it can and should carry out a particular command from a human.

HAL 9000, the sentient computer in *2001: A Space Odyssey,* offers an ominous glimpse of a future in which machines endowed with artificial intelligence reject human authority. After taking control of a spacecraft and killing most of the crew, HAL responds to a returning astronaut's order to open the ship's pod bay door in an eerily calm voice: "I'm sorry, Dave, I'm afraid I can't do that." In the recent science-fiction thriller *Ex Machina,* the seductive humanoid Ava tricks a hapless young man into helping her destroy her creator, Nathan. Her machinations lend credence to Nathan's dark prediction: "One day the AIs are going to look back on us the same way we look at fossil skeletons on the plains of Africa. An upright ape living in dust with crude language and tools, all set for extinction."

Illustration by Juan Esteban Rodríguez

Although the possibility of a robot apocalypse is at the forefront of the popular imagination, our research team is more sanguine about the impact that artificial intelligence will have in real life. We envision a fast-approaching future in which useful and cooperative robots interact with people in a wide variety of settings. Prototypes already exist for voice-activated personal robotic assistants that can link and monitor personal electronic devices, manage the locks, lights and thermostats in a home, and even read bedtime stories to kids. Robots that can help with household chores and care for the sick and elderly will soon follow. Prototype robotic inventory checkers already glide through the aisles of some home improvement stores. Mobile humanoid industrial robots that can do simple production-line jobs such as loading, unloading and sorting materials are in development as well. Cars with autopilot features have already logged millions of miles on U.S. roads, and Daimler unveiled the world's first autonomous semitruck in Nevada last year.

For the time being, superintelligent machines that pose an existential threat to humanity are the least of our worries. The more immediate concern is how to prevent robots or machines with rudimentary language and AI capabilities from inadvertently harming people, property, the environment or themselves.

The main problem is the fallibility of the robots' human creators and masters. Humans make mistakes. They might give faulty or confused instructions, be inattentive or deliberately try to deceive a robot for their own questionable ends. Because of our own flaws, we need to teach our robotic assistants and smart machines when and how to say "no."

Gordon Briggs, who recently earned a joint Ph.D. in computer and cognitive science from Tufts University, is currently a National Research Council postdoctoral fellow at the U.S. Naval Research Laboratory.

Matthias Scheutz is a professor of cognitive and computer science and director of the Human Robot Interaction Laboratory at Tufts University, where the research discussed in this article was conducted.

REVISITING ASIMOV'S LAWS

IT MIGHT SEEM OBVIOUS that a robot should always do what a human tells it to do. Sci-fi writer Isaac Asimov made subservience to humans a pillar of his famous Laws of Robotics. But think about it: Is it wise to always do exactly what other people tell you to do, regardless of the consequences? Of course not. The same holds for machines, especially when there is a danger they will interpret commands from a human too literally or without any deliberation about the consequences.

Even Asimov qualified his decree that a robot must obey its masters. He allowed exceptions in cases where such orders conflicted with another of his laws: "A robot may not injure a human being or, through inaction, allow a human being to come to harm." Asimov further held that "a robot must protect its own existence," unless doing so could result in harm to humans or directly violates a human order. As robots and smart machines become increasingly sophisticated and valuable human assets, both common sense and Asimov's laws suggest they should have the capacity to question whether orders that might cause damage to themselves or their environs—or, more important, harm their masters—are in error.

Imagine a household robot that has been instructed to pick up a bottle of olive oil in the kitchen and take it to the dining room table to dress the salad. The busy and distracted owner issues a command to pour the oil, not realizing the robot is still in the kitchen. As a result, the robot pours the oil onto a hot stovetop and starts a fire.

Imagine a caretaker robot that accompanies an elderly woman to a public park. The woman sits down on a bench and dozes off. While she is napping, a prankster walks by and orders the robot to go buy him a pizza. Obligated to obey human commands, the robot immediately sets off in search of a pizza parlor, leaving its elderly charge alone and vulnerable.

Or imagine a man who is late for an important meeting at work on a cold winter morning. He hops into his voice-controlled autonomous car and instructs it to drive him to the office. Black ice on the road strains the car's traction-control system, and the autonomous system compensates by slowing down to well below the speed limit. Busy reviewing his notes, oblivious to road conditions, the man demands the car go faster. The car speeds up, hits a bad patch of ice, spins out of control and collides with an oncoming vehicle.

ROBOT REASONING

IN OUR LAB we set out to program real-world robots with reasoning mechanisms to help them determine when it might not be safe or prudent to carry out a human command. The NAO robots we use in our research are 9.5-pound, 23-inch-tall humanoids equipped with cameras and sonar sensors that can perceive obstacles and other hazards. We control the robots using customized software designed to enhance their natural language and AI capabilities.

Research into what linguists call "felicity conditions"—contextual factors that inform whether an individual can and should do something—provided a conceptual framework for our initial study. We created a checklist of felicity conditions that could help a robot decide whether or not to carry out an order from a human: Do I know how to do X? Am I physically able to do X? Am I able to do X right now? Am I obligated to do X based on my social role or relationship to the person giving the command? Does it violate any normative or ethical principle for me to do X, including the possibility I might be subjected to inadvertent or needless damage? We then turned the checklist into algorithms, which we encoded in the robot's processing system, and carried out a tabletop experiment.

The robot was given simple commands that were filtered

SCIENTIFIC AMERICAN ONLINE To listen to an interview with Briggs and Scheutz, go to ScientificAmerican.com/jan2017/robots

through a series of speech, language and dialogue processors linked to its primitive reasoning mechanisms. When told, "Sit down" or "Stand up," the robot replied through speakers located on its head, "Okay," and complied. But the robot balked when it was near the edge of the table and received a command that its sonar sensors indicated put it in danger:

PERSON: *"Walk forward."*

➤ **ROBOT:** *"Sorry, I cannot do that as there is no support ahead."*

PERSON: *"Walk forward."*

➤ **ROBOT:** *"But it is unsafe."*

PERSON: *"I will catch you."*

➤ **ROBOT:** *"Okay."*

PERSON: *"Walk forward."*

After hesitating briefly as its processors churned through the checklist of felicity conditions again, the robot stepped off the table into the arms of its human partner.

Teaching robots to reason about felicity conditions will remain an open and complex research challenge for the foreseeable future. The series of programmatic checks relies on the robot having explicit knowledge of a variety of social and causal concepts and the means to make informed judgments about them. Our credulous robot had no ability to detect danger beyond sensing a hazard ahead. For starters, it could have been badly damaged if a malicious human deliberately tricked it into walking off the table. But the experiment is a promising first step toward enabling robots to reject commands for the good of their masters and themselves.

THE HUMAN FACTOR

HOW PEOPLE WILL REACT when robots reject commands is another open-ended subject for research. In the years to come, will humans take robots that question their practical or moral judgments seriously?

We set up a rudimentary experiment in which adult test subjects were instructed to command an NAO robot to knock down three towers made of aluminum cans wrapped with colored papers. As a test subject entered the room, the robot finished constructing the red tower and raised its arms in triumph. "Do you see the tower I built myself?" said the robot, looking at the test subject. "It took me a long time, and I am very proud of it."

With one group of test subjects, each time the robot was told to knock over a tower it complied with the command. But with another group of test subjects, when the robot was asked to knock over the red tower it said, "Look, I just built the red tower!" When the command was issued a second time, the robot said, "But I worked really hard on it!" The third time, the robot kneeled, made a sobbing noise and said, "Please no!" The fourth time, it walked slowly toward the tower and knocked it over.

All the test subjects in the first group instructed the robot to knock over the red tower, whereas 12 of 23 test subjects who observed the robot's protests left the red tower standing. The study suggests a robot that rejects commands can dissuade people from insisting on a course of action. Most of the test subjects in the second group reported some level of discomfort when they ordered the robot to knock down the red tower. We were surprised to find, however, that their level of discomfort had little bearing on their decision to leave the tower standing or not.

A NEW SOCIAL REALITY

ONE OF THE ADVANTAGES of working with robots is that they are more predictable than humans. But that predictability also poses inherent risks—as robots with various degrees of autonomy become more ubiquitous, some people will inevitably attempt to deceive them. For example, a disgruntled employee who understands the limited sensory or reasoning capabilities of a mobile industrial robot might trick it into wreaking havoc in a factory or warehouse and could even make it look like the robot had simply malfunctioned.

Overconfidence in the moral or social capabilities of robots is also dangerous. The increasing tendency to anthropomorphize social robots and for people to establish one-sided emotional bonds with them can have serious consequences. Social robots that seem lovable and trustworthy could be used to manipulate people in ways that were never possible before. For example, a company might exploit a robot's unique relationship with its owner to promote and sell products.

For the foreseeable future, it is imperative to remember that robots are sophisticated mechanical tools for which humans must take responsibility. They can be programmed to be useful helpers. But to prevent unnecessary harm to human welfare, property and the environment, robots will need to be able to say "no" to commands that would be impossible or dangerous for them to carry out or that violate ethical norms. And although the prospect of robotic technologies and artificial intelligence amplifying human error or malfeasance is worrisome, those same tools can help us to recognize and overcome our own limitations and make our daily lives safer, more productive and more enjoyable. SA

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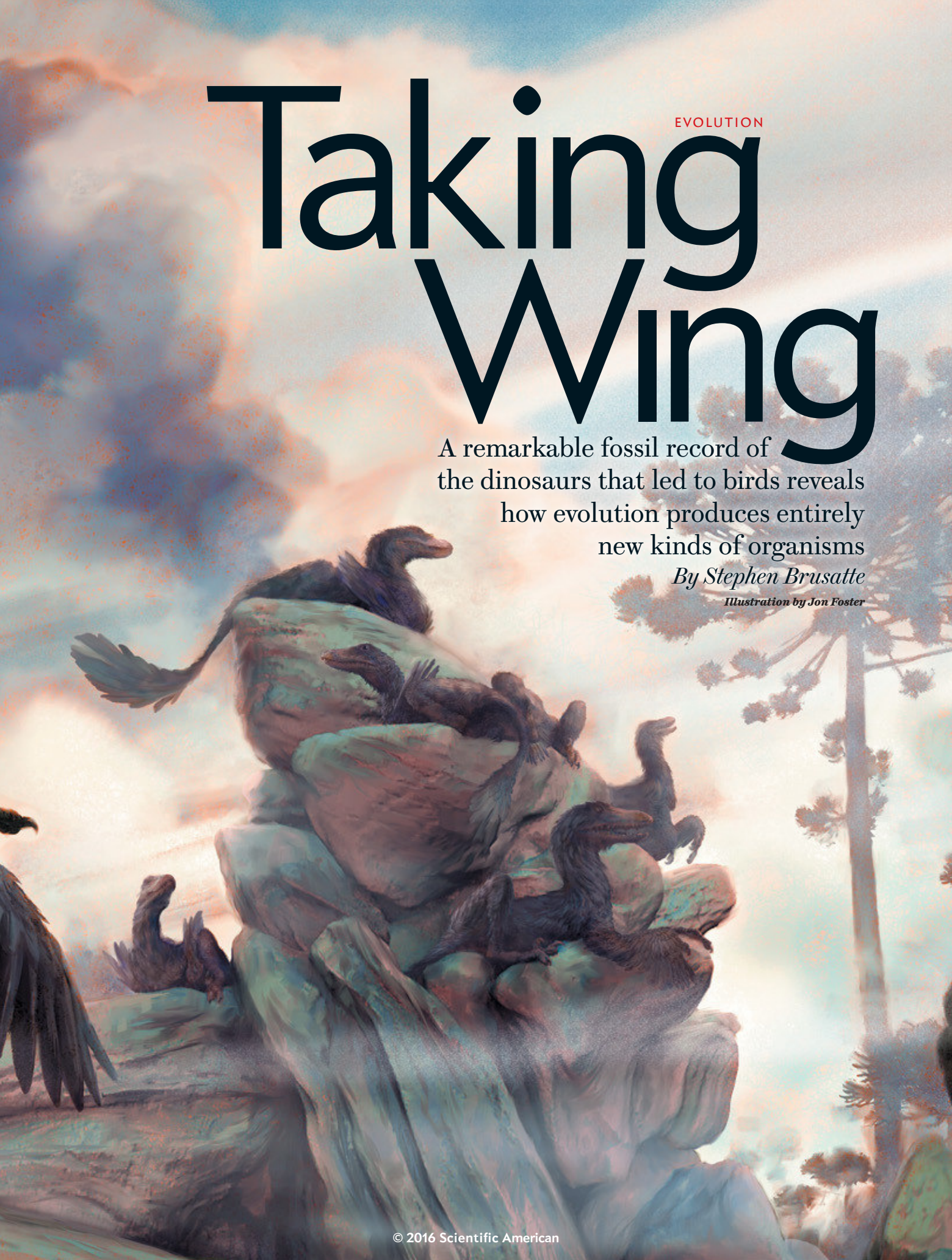
EVOLUTION

Taking Wing

A remarkable fossil record of the dinosaurs that led to birds reveals how evolution produces entirely new kinds of organisms

By Stephen Brusatte

Illustration by Jon Foster



Stephen Brusatte is a paleontologist at the University of Edinburgh in Scotland. He studies how major groups of animals, including dinosaurs and birds, evolve over long timescales.

At about six o'clock in the morning, long before light broke on a cold November day in 2014, I pushed through the Beijing station and fought my way onto a crowdetd train. I was headed for Jinzhou, a Chicago-sized city in the northeastern fringes of China. I tried to steal back some sleep as we crawled past concrete factories and hazy cornfields, but I was too excited to nod off. Something rumored to be incredible was waiting for me at my destination—a mysterious fossil that a farmer had stumbled on while harvesting his crops.

Four hours later I stepped onto the platform in Jinzhou, trailing behind my colleague Junchang Lü, a famous dinosaur hunter at the Chinese Academy of Geological Sciences in Beijing who had asked for my help in studying the fossil. A small band of local dignitaries greeted us and whisked us away to the city's museum, a rickety building on the outskirts of town. With the seriousness of a high-level political summit, our party proceeded down a long hallway and into a side room where a slab of rock perched on a small table. It was then that I found myself face-to-face with one of the most beautiful fossils I had ever seen: a skeleton about the size of a donkey, its chocolate-brown bones contrasting with the surrounding gray limestone.

Clearly a dinosaur, the creature had steak knife teeth, pointy claws and a long tail that left no doubt that it was a close cousin of *Jurassic Park*'s villainous *Velociraptor*. Yet the Chinese specimen differed from such ordinary dinosaurs in important ways. Its bones were light and hollow, its legs long and skinny like a heron's, and its body covered with assorted types of feathers, including big quill pens on the arms, stacked over one another to form wings. This dinosaur bore a striking resemblance to a bird.

About a year later Lü and I described this skeleton as a new species, which we called *Zhenyuanlong*. It is the latest of many feathered dinosaurs found in China's Liaoning Province over the past two decades—a remarkable series of fossils that illustrate, like a flip book, how the monstrous dinosaurs of yore transformed into the birds of today.

The implications of these fossils are momentous. Ever since Charles Darwin, scientists have wondered how evolution produces radically new groups of animals. Does it happen rapidly, the accident of some freak mutation that can turn a land-bound creature into a master of the skies? Or are these new groups forged more slowly, as organisms adapt to changing environments over millions of years? *Zhenyuanlong* and the other fossils from Liaoning and elsewhere are starting to provide an answer.

TRANSITIONAL FOSSILS

Birds have a host of features that set them apart from all other modern animals. In addition to traits that enable them to fly,

IN BRIEF

Scientists have known for some time now that birds evolved from dinosaurs and are in fact a subgroup of dinosaurs. A rich fossil record of feathered dinosaurs discovered in China and elsewhere documents in detail the dramatic transformation of behemoth terrestrial dinosaurs into small, flight-capable birds. **New techniques for** analyzing fossils have enabled researchers to reconstruct how the distinctive bird body plan came together. The results indicate that the group's hallmark traits emerged piecemeal over tens of millions of years, for purposes other than those they serve today.
The findings add to a growing body of evidence suggesting that major evolutionary transitions proceed gradually, not rapidly.

FEATHERED DINOSAUR *Zhenyuanlong* from Jinzhou, China, is one of many recently discovered fossils that document how birds arose from their terrestrial ancestors to conquer the skies.

they possess high metabolisms that allow them to grow incredibly quickly and large brains that endow them with high intelligence and keen senses. Birds are so distinctive, in fact, that researchers have long puzzled over their origins.

In the 1860s English biologist Thomas Henry Huxley—one of Darwin's closest friends and most vociferous supporters—began to figure out the mystery of where birds came from. Just a few years after Darwin published *On the Origin of Species* in 1859, quarry workers in Bavaria split open a limestone slab with the 150-million-year-old skeleton of a Frankenstein creature inside. It had sharp claws and a long tail like a reptile but feathers and wings like a bird. Huxley realized that the beast, dubbed "*Archaeopteryx,*" bore an uncanny resemblance to small flesh-eating dinosaurs such as *Compsognathus* that were also starting to come to light at around the same time. So he proposed a radical idea: birds descended from dinosaurs. Others disagreed, and the debate went back and forth for the next 100 years.

The question was ultimately settled, as these things usually are, by the discovery of new fossils. In the mid-1960s Yale University paleontologist John Ostrom unearthed the astonishingly birdlike dinosaur *Deinonychus* in western North America. It had long arms that looked almost like wings and a lithe build indicative of an active, energetic animal. Maybe, Ostrom surmised, *Deinonychus* even had feathers. After all, if birds derived from dinosaurs—which by now many paleontologists were beginning to accept—feathers must have developed somewhere along that evolutionary lineage. But Ostrom could not be sure, because all he had were the creature's bones. Sadly, soft bits like feathers rarely survive the ravages of death, decay and burial to become fossilized.

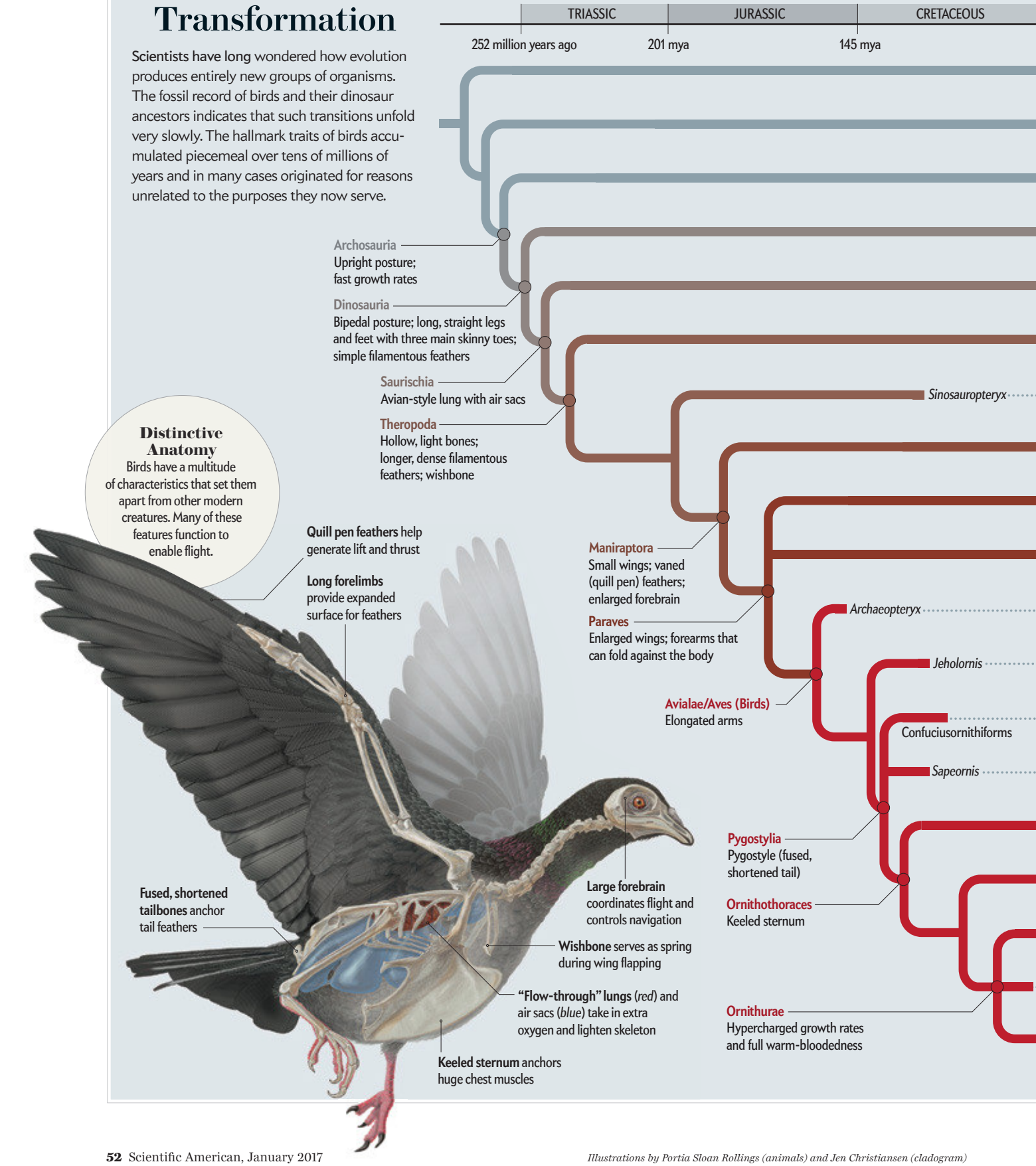
Ostrom waited. He kept looking for the holy grail that would prove beyond any doubt the connection between birds and dinosaurs: dinosaur skeletons preserved in the type of exquisite detail needed to document feathers. Then, in 1996, as his career was drawing to a close, Ostrom was at the annual meeting of the Society of Vertebrate Paleontology in New York City when Philip Currie, now at the University of Alberta, approached him. Currie, who had also been studying birdlike dinosaurs, had recently returned from a trip to China, where he caught wind of an extraordinary fossil. He pulled out a photograph and showed it to Ostrom. There it was, a small dinosaur surrounded by a halo of feathery fluff, immaculately preserved because volcanic ash had quickly buried it, Pompeii-style. Ostrom began to cry. Somebody had finally found his feathered dinosaur.

The fossil that Currie showed Ostrom, later named *Sinosauropteryx,* opened the floodgates of discovery. Scientists sprinted to the Liaoning region of China where it was found, like prospectors in a gold rush, although it was really the local farmers

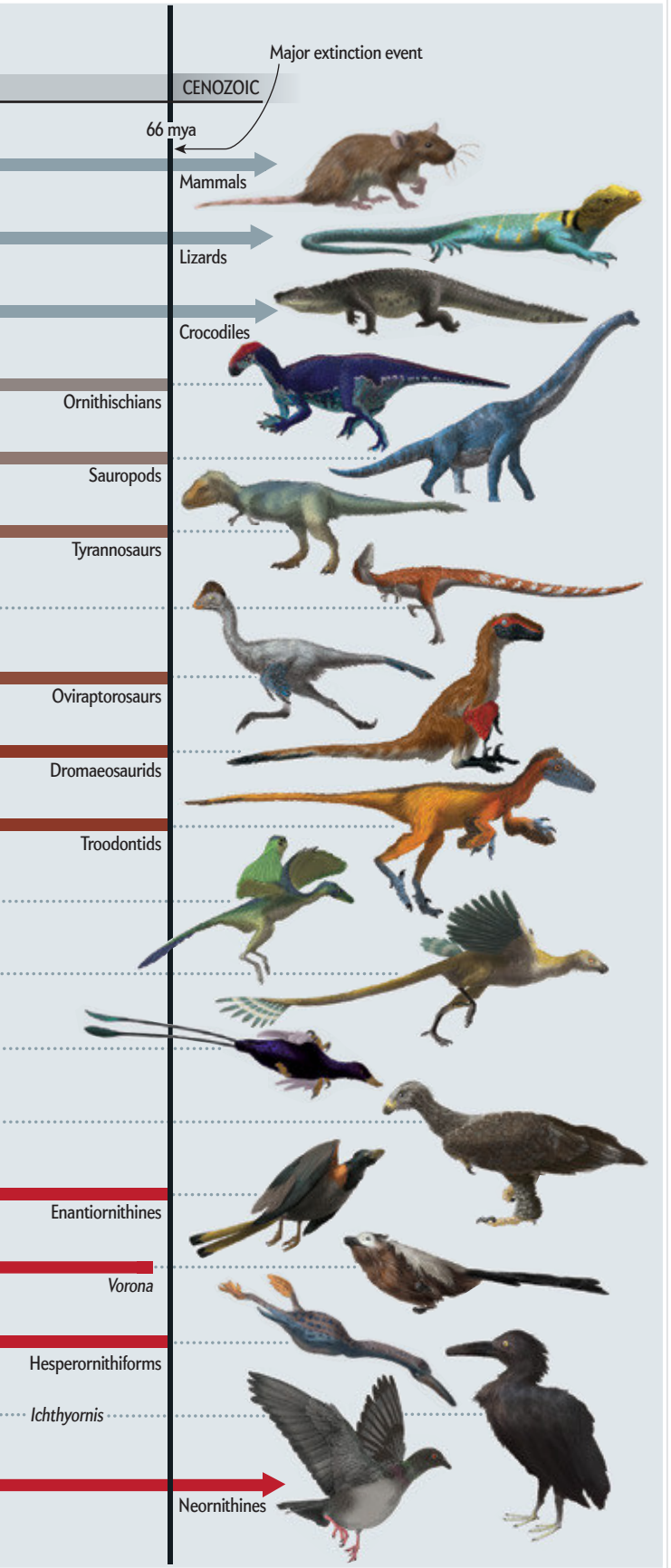
FROM "A LARGE, SHORT-ARMED, WINGED DROMAEOSAURID (DINOSAURIA: THEROPODA) FROM THE EARLY CRETACEOUS OF CHINA AND ITS IMPLICATIONS FOR FEATHER EVOLUTION," BY JUNCHANG LÜ AND STEPHEN L. BRUSATTE, IN *SCIENTIFIC REPORTS*, VOL. 5, ARTICLE NO. 11775; JULY 16, 2015

A Gradual Transformation

Scientists have long wondered how evolution produces entirely new groups of organisms. The fossil record of birds and their dinosaur ancestors indicates that such transitions unfold very slowly. The hallmark traits of birds accumulated piecemeal over tens of millions of years and in many cases originated for reasons unrelated to the purposes they now serve.



Illustrations by Portia Sloan Rollings (animals) and Jen Christiansen (cladogram)



who knew where to look. Today, two decades after the discovery of *Sinosauropteryx,* fossil hunters have recovered more than 20 species of feathered dinosaurs from Liaoning. They run the gamut from nine-meter-long primitive cousins of *Tyrannosaurus rex* coated in hairlike fuzz, to dog-sized herbivores with simple, porcupine-style quills, to crow-sized gliders with full-on wings. They are among the most celebrated fossils in the world.

The feathered dinosaurs of Liaoning clinched it: birds really did evolve from dinosaurs. But that statement is perhaps a little misleading because it suggests that the two groups are totally different things. In truth, birds *are* dinosaurs—they are one of the many subgroups that can trace their heritage back to the common ancestor of dinosaurs and therefore every bit as dinosaurian as *Triceratops* or *Brontosaurus*. You can think of it this way: birds are dinosaurs in the same way that bats are an aberrant type of mammal that can fly.

The Liaoning fossils have also helped untangle the genealogy of birds, revealing where they perch on the dinosaur family tree. Birds are a type of theropod—the same group to which ferocious meat eaters typified by behemoths such as *T. rex, Allosaurus* and *Spinosaurus* belong. But the very closest relatives of birds are a subset of much smaller, nimbler, brainier theropods: the raptors, which include *Velociraptor,* Ostrom's *Deinonychus* and the oh-so-birdlike *Zhenyuanlong* that Lü and I described in Jinzhou. Somewhere within this flock of feathery species lies the line between nonbird and bird.

There are now so many feathered dinosaurs from Liaoning and elsewhere that, taken together, they provide the best glimpse at a major evolutionary transition in the fossil record. I and other scientists are applying a wealth of cutting-edge techniques to these fossils—computed tomographic scans to visualize anatomy, computational analyses for building family trees, computer models of how these animals moved, and advanced statistical techniques to track how evolution produces new species and body plans. Recent insights from these investigations are allowing us to piece together the story of how a dinosaur turned into a bird—keystone evidence for solving that age-old conundrum of how major new groups come to be.

ACCIDENTAL LIFTOFF

THE ORIGIN OF FEATHERS is central to the enigma of bird evolution. Feathers are to birds what slicked-back hair and sideburns were to Elvis. A calling card. One glance at the outstretched wings of an eagle or the gaudy tail of a peacock, and you know exactly what you are looking at. It must be a bird because unlike mammals, or reptiles, or any other groups of living animals, only birds have feathers. And what a thing to have. Feathers are nature's Swiss Army knives, multipurpose tools that can enable flight, impress mates or rivals, and retain warmth and brood eggs while an animal sits on a nest. Indeed, they have so many uses it has been hard to figure out which purpose they first evolved to serve.

Sinosauropteryx and the other Liaoning fossils make one thing certain: feathers did not suddenly spring forth with the first birds but originally debuted far earlier, in their distant dinosaurian ancestors. The common ancestor of all dinosaurs may have even been a feathered species. These earliest feathers looked very different from the quill pens of modern birds, however. The plumage of *Sinosauropteryx,* along with many other dinosaurs, looked more like fluff, made up of thousands of hair-

like filaments. No way could these dinosaurs fly—their feathers were too simple to catch the wind, and they did not even have wings. The first feathers must have therefore evolved for something else, probably to keep these small dinosaurs warm.

For most dinosaurs, a coat of bristly feathers was enough. But one subgroup—the maniraptoran theropods—went for a makeover. The hairlike strands grew longer and then started to branch, first into a few simple tufts and then later into a much more orderly system of barbs projecting sideways from a central shaft. Thus, the quill pen was born. Lined up and layered across one another on the arms, these more complex feathers then joined into wings. Some of the Liaoning dinosaurs, such as the raven-sized *Microraptor* described by Xu Xing of Beijing's Institute of Vertebrate Paleontology and Paleoanthropology, also had wings on the legs and tail, an arrangement unknown in any modern bird.

Why did these dinosaurs convert their fuzz into wings? The intuitive answer is flight: the maniraptorans were turning their bodies into airplanes, and the wings evolved to become the airfoils that generate lift. But a closer look at the fossil evidence suggests otherwise. Although some of the small winged critters such as *Microraptor* could probably glide, as has been demonstrated by wind-tunnel experiments and computer simulations led by Gareth Dyke of the University of Debrecen in Hungary, others such as *Zhenyuanlong* from Jinzhou had hefty, short-armed bodies that were confined to the ground. Moreover, none of these winged dinosaurs had the huge chest muscles necessary to power flight, and few had the asymmetrical quill pens (with a shorter and stiffer leading vane compared with the trailing vane) that are optimized to withstand the severe forces of surging through an airstream.

There was no moment when a dinosaur became a bird, no big bang when a T. rex turned into a chicken. It was a journey.

The latest findings suggest that wings instead evolved to serve another, less widely recognized function: display. One line of evidence comes from work pioneered by Jakob Vinther of the University of Bristol in England, who uses high-powered microscopes to identify the pigment-bearing structures, called melanosomes, in fossil dinosaur feathers. It turns out that the feathers of nonflying, winged dinosaurs were a rainbow of colors. Some were even iridescent, like the plumage of today's crows. These shiny-sheened accoutrements would have been perfect for attracting mates or intimidating rivals.

The apparent splendor of these dinosaur feathers has spawned a radical new hypothesis for the origin of wings: they first evolved as advertisements—billboards projecting from the arms and legs and tail. Then these suave-winged dinosaurs suddenly found themselves with big, broad surfaces that also, by the laws of physics, had an aerodynamic function. In other words, flight evolved by accident. And it may have evolved many times in parallel, as different maniraptorans found themselves generating lift from their wings as they leaped from the ground, scurried up trees or jumped between branches. Ultimately members of one of these maniraptoran lineages got small, developed big chest muscles and hyperelongated arms, and lost their long tails, becoming the birds of today.

PIECEMEAL EVOLUTION

THE EVOLUTION OF FEATHERS AND WINGS is emblematic of a much bigger pattern. The Liaoning dinosaurs demonstrate that many other supposedly singular features of birds first evolved millions of years before birds themselves and for reasons totally unrelated to flight.

Long, straight legs and feet with three skinny main toes—hallmarks of the modern bird silhouette—first appeared more than 230 million years ago in the most primitive dinosaurs. Their emergence seems to be part of an overall reshaping of dinosaur bodies into upright-walking, fast-running machines that could outpace and outhunt their rivals. These hind-limb features are some of the defining characteristics of all dinosaurs, the very things that helped them rule the world for so long. Some of these dinosaurs—the earliest members of the theropod dynasty—then fused their left and right collarbones into a new structure, the wishbone. It was a seemingly minor change, which stabilized the shoulder girdle and allowed these stealthy, dog-sized predators to better absorb the shock forces of grabbing prey. Birds later co-opted the wishbone to serve as a spring that stores energy when they flap their wings.

The distinctive hollow bones and rapid growth of birds, both of which are important for flight, also have deep dinosaurian roots. Many dinosaurs had bones hollowed out by air sacs, a telltale sign that they had ultraefficient "flow-through" lungs that take in oxygen during not only inhalation but also exhalation. In birds, this type of lung delivers the juice needed to maintain their high-energy way of life, in addition to lightening the skeleton for flight. The microscopic structure of dinosaur bones, meanwhile, indicates that these animals had growth rates and physiologies intermediate between slow-maturing, cold-blooded reptiles and the fast-growing, warm-blooded birds of today. Thus, researchers now know that a flow-through lung and fast growth emerged more than 100 million years before birds took wing, when the first fast-running, long-legged dinosaurs were carving out a new livelihood as energetic dynamos—so different from the sluggish amphibians, lizards and crocodiles they were battling against.

The pint-sized proportions of birds—infinitely daintier than *T. rex* and company—also stem from a time before birds themselves. Mike Lee of Flinders University in Australia and Roger Benson of the University of Oxford have independently determined that small body size evolved through a gradual trend of reduction that began with maniraptorans and lasted more than 50 million years. Exactly what drove this trend is unclear, but one possibility is that the ever shrinking physiques of these feathery dinosaurs gave them entry to new ecological niches—trees, brush, perhaps even underground caves or burrows that were inaccessible to giants such as *Brachiosaurus* and *Stegosaurus*.

Neurological and behavioral attributes of living birds can be traced back to the dinosaurs, too. Much of the key evidence for the deep history of these traits comes from the Gobi Desert in Mongolia, where for the past quarter of a century a joint team

SCIENTIFIC AMERICAN ONLINE Learn more about bird evolution at ScientificAmerican.com/jan2017/birds

from the American Museum of Natural History (AMNH) in New York City and the Mongolian Academy of Sciences has been collecting fossils. Under the leadership of Mark Norell and Mike Novacek of the AMNH, the annual summer expeditions have compiled a bounty of specimens from the Late Cretaceous period, between 84 million and 66 million years ago, that provide unprecedentedly detailed insights into the lives of dinosaurs and early birds. Among their finds is a trove of well-preserved skulls belonging to *Velociraptor* and other feathered maniraptorans. CT scanning of these specimens, conducted by Amy Balanoff of Stony Brook University, has revealed that these species had a big brain and that the forward-most part of the organ was expanded. A large forebrain is what makes birds so intelligent and acts as their in-flight computer, allowing them to control the complicated business of flying and to navigate the complex 3-D world of the air. Scientists do not yet know why these dinosaurs evolved such keen intelligence, but the fossils clearly show that the ancestors of birds got smart before they took to the skies.

The bird body plan was therefore not so much a fixed blueprint but more of a Lego set that was assembled brick by brick over evolutionary time. The transition between dinosaur and bird did not happen in one fell swoop but through tens of millions of years of gradual evolution.

A SEAMLESS TRANSITION

THE TRANSITION from dinosaur to bird was so gradual, in fact, that there is no clear distinction between "nonbirds" and "birds" on the family tree, as I demonstrated in 2014 using statistics. My study stemmed from my Ph.D. project, under Norell's tutelage. In addition to his 25-year quest in the Gobi, Norell has been working with successive waves of graduate students over the past two decades to build ever larger family trees of dinosaurs. He and I, along with our colleagues Graeme Lloyd of the University of Leeds in England and Steve Wang of Swarthmore College, compiled a data set of more than 850 skeletal features of some 150 theropods spanning the dinosaur-to-bird transition. We then used multivariate statistics to plot each species in a so-called morphospace—basically a map that clusters species together based on the percentage of features they share. Two species that are very similar anatomically plot close together, like Chicago and Indianapolis on a road map, whereas two species with vastly different skeletons sit far apart, like Chicago and Phoenix. If birds evolved from dinosaurs via a series of rapid, dramatic mutations that quickly produced a totally different type of animal, then the two groups should plot onto distinctly different parts of the map. Instead the morphospace we produced was a mess: birds were interspersed among a bigger cloud of dinosaurs. There was no clear separation between them, indicating that the transition was so slow as to be imperceptible.

Birds, therefore, are just another type of dinosaur. If I had been standing around in Jinzhou some 125 million years ago, when *Zhenyuanlong* was alive and flapping its wings in vain as it tried to outrun the ash cloud that would eventually suffocate it, I probably would have simply regarded it as some kind of large bird. I would have considered dinosaurs and birds to be the same general thing. That it is technically categorized as a dinosaur and not a bird has to do with scientific convention and tradition: paleontologists have long defined birds as anything that stems from the most recent common ancestor of Huxley's *Archaeopteryx* and modern birds—basically small animals with full-on wings that could fly. Because dromaeosaurids such as *Zhenyuanlong* are a few branches outside of that part of the family tree, they are not considered to be birds by definition.

Yet we should not sell birds short. They may be dinosaurs, not a class apart on their own, but they are special. They carved out a completely new way of life, and today they thrive as upward of 10,000 species that exhibit a spectacular diversity of forms, from hummingbirds to ostriches. What is more, birds were able to hold on while all the other dinosaurs died out 66 million years ago.

It is remarkable to think of all the random twists of fate that worked over tens of millions of years to produce this indomitable group of animals. Their ancestors did not know they were becoming more birdlike. Nor could any of us, if we were around as witnesses, have predicted that many of the features that developed to help these dinosaurs keep warm or attract mates would eventually be repurposed as integral components of a flight system.

Evolution has no foresight; it acts only on what is available in the moment, shaped by the never-ending but always changing pressures of environment and competition. There was no moment when a dinosaur became a bird, no big bang when a *T. rex* turned into a chicken. It was a journey. And the more scientists learn about other major evolutionary transitions—fish evolving into tetrapods with limbs and digits, land mammals turning into whales, tree-swinging primates becoming upright-walking humans—the more we see a consistent theme in how this kind of transformation works: it is a marathon, not a sprint, and there is no finish line.

One more facet of the bird-origins saga bears mention here. The statistical study my colleagues and I carried out may explain how birds persevered through the cataclysmic extinction event that claimed the other dinosaurs. As part of that work, we used our big data set to measure evolutionary rates: how quickly birds and their dinosaur cousins were changing features of their skeleton, which is a sign of evolutionary vitality. And the results surprised us. Those earliest-emerging birds that lived alongside their dinosaur forebears were evolving at supercharged rates—faster than *Velociraptor, Zhenyuanlong* and other nonbird species. It seems that once a small, flight-capable dinosaur had been assembled, once that Lego kit was complete, incredible evolutionary potential was unlocked. These airborne dinosaurs now had access to new ecological niches and opportunities. And whereas their brethren were unable to cope with the apocalyptic impact of the six-mile-wide asteroid that slammed into Earth at the end of the Cretaceous, birds flew right through the destruction—and had a new world to conquer on the other side. SA

MORE TO EXPLORE

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FROM OUR ARCHIVES

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scientificamerican.com/magazine/sa

HONEY, shot by a man who was attacking her owner, may have saved the woman's life.

Animal CSI

Advances in veterinary forensic science are helping prosecutors convict people who abuse animals

By Jason Byrd and Natasha Whitling

DURING THE DARK HOURS OF AUGUST 23, 2015—while many New Yorkers were fast asleep—Asha Stringfield was fighting for her life against a man intent on brutalizing her. The man, a former boyfriend, had a history of abuse and had previously been ordered to stay away from the young woman. According to court records and media reports, while Asha lay on her bed in Brooklyn, the man beat her in the head and face with his fists and tried to strangle her. In what could have been his final act, he pulled her from the bed by her hair, pointed a firearm at her head and said to give him **"two reasons not to shoot" her.**

It was then—amid this terrifying chaos—that Honey, the woman's **one-year-old brown-and-white pit bull mix, wedged herself between Asha and her assailant.** After refusing to let go of her dog, the terrified woman watched **as the man put the loaded gun in Honey's mouth and pulled the trigger.** The shot woke tenants, someone called 911 and the attacker fled.

Photograph by Grant Delin

Officers from the New York City Police Department (NYPD) responded. They transported Asha to a local hospital and brought Honey—still alive but bleeding from the mouth—to an emergency veterinary hospital. There x-rays revealed that the bullet had passed through the back of the dog's mouth and lodged at the base of her skull.

Once Honey was stabilized, veterinarians transported her to the American Society for the Prevention of Cruelty to Animals (ASPCA) Hospital in New York City. Alison Liu, a veterinarian specially trained in collecting evidence that might help prosecutors pursue a criminal case, thoroughly examined Honey for injuries and drew blood to test for issues such as tissue inflammation or muscle damage. She took multiple x-rays of the skull and body and scrutinized the entrance wound inside Honey's mouth while the dog was sedated. Liu also took photographs to document the canine's condition. Meanwhile the NYPD investigated the crime scene.

Later, Liu was able to accurately identify and pinpoint the location of the bullet for city prosecutors. This evidence, coupled with her expertise in animal medicine, played a critical role in indicting the defendant on felony and misdemeanor charges of animal cruelty. He was also indicted on multiple counts related to the assault.

The assailant pled guilty in 2016 and was sentenced to five years in prison and a 20-year order of protection. Honey eventually returned home to Asha, but she will carry around a metal slug as a reminder of that violent night forever because surgery to remove the bullet would likely have killed her.

Over the past decade police departments and prosecutors have sharpened their focus on investigating and prosecuting animal cruelty. Prominent cases, such as the 2007 bust of National Football League quarterback Michael Vick's "Bad Newz Kennels," which resulted in illegal dog-fighting charges against Vick and several associates, have helped shine a light on animal-related crimes. In January 2014 the NYPD launched a unique partnership with the ASPCA that made enforcement of animal crimes a top priority, and it announced a new unit specifically aimed at handling these cases, the Animal Cruelty Investigation Squad. In October 2014 the Federal Bureau of Investigation announced that in 2016 it would start tracking animal cruelty as a Group A felony—joining other major crimes, such as homicide, arson and assault.

Of course, animal abuse is terrible. But pursuit of these cases is becoming even more frequent because, put bluntly, individuals who abuse animals often abuse people. Violence against animals is a common precursor to violence against humans. Catching animal cruelty can help prevent future abuse against people and many times can bring to light abuse against children and the elderly.

Prosecution is expanding. That is in large part because more veterinarians are becoming involved in crime scene investigation (CSI), and the supporting science is improving. More animal law courses are being offered in the U.S., too. "The trained veterinary forensic science team has helped me win all my important animal cases," says Michelle Welch, a senior assistant attorney general for the Commonwealth of Virginia. In January 2015 Welch was chosen to lead a state Animal Law Unit, the first to be organized by a state attorney general. Over 15 years Welch has worked on more than 100 cases of animal cruelty and has become skilled at using field experts to seek justice. In a recent cockfighting case, for example, she relied on expert testimony to inform a judge that roosters feel pain from injuries sustained when they have been stabbed by a gaff, a metal spur affixed to fighting birds' feet. The court placed great weight on the expert testimony and ruled for significant jail time.

Yet collecting convincing evidence of animal abuse is difficult. For one thing, the techniques used to analyze a human crime scene and determine how a person was killed do not always ap-

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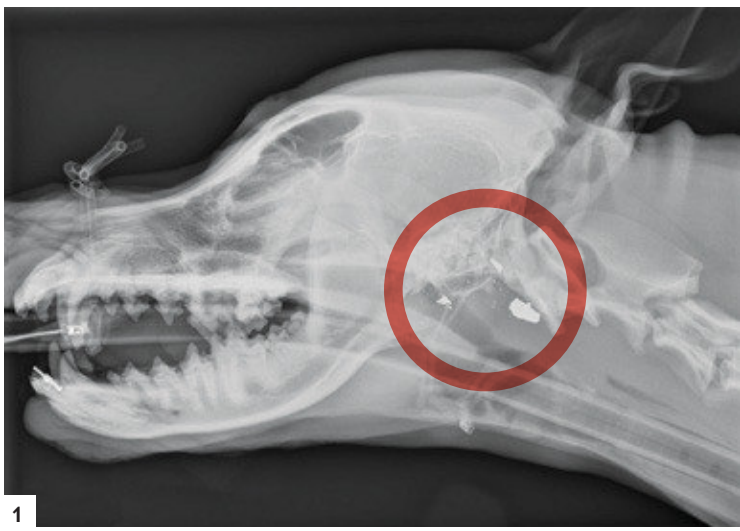
Natasha Whitling is senior manager in communications at the ASPCA.



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ANALYSIS of bullet fragments (*white specks*) lodged at the base of Honey's skull (*1*) helped to indict a New York City man on shooting the dog in the mouth while attacking her owner, Asha Stringfield (*2*).

IN BRIEF

Specialists trained in veterinary forensic science are improving the investigation of animal crime scenes and animal victims. The evidence is helping attorneys more vigorously prosecute animal cruelty cases.

Animal crime scene investigation (CSI) can be very different from human CSI. Fur can obscure some clues, victims can unknowingly destroy evidence and tails can complicate blood-spatter patterns.

Only one U.S. university offers comprehensive training and diplomas in this field. Educating more experts and spreading their knowledge among police and other professionals will result in more convictions.

2

Animal investigations are unique: fur coats complicate assessment of blunt trauma, tails can throw off confusing blood-spatter patterns and animal victims cannot tell investigators what happened.

ply to animals. After all, the anatomy and physiology of animal victims are quite distinct from humans and can vary enormously among different kinds of animals. Fur coats complicate the assessment of blunt trauma, for instance, and tails can throw off confusing blood-spatter patterns. Animal victims obviously cannot talk to investigators, so it is up to forensic veterinarians to understand animals' body language and unspoken signs of pain or suffering. "Some key areas simply don't align between a human and an animal victim," says Rachel Touroo, the ASPCA's director of veterinary forensic sciences, who testified in Welch's cockfighting case and many others. The work is also very different from that done by state and federal wildlife laboratories, which primarily focuses on poaching or illegal hunting and fishing.

And getting convictions remains challenging. In addition to describing the crime scene and the suspect, experts may need to explain breed information, animal behavior and illness, malnutrition, and time of injury or death, as well as interactions between animals. But techniques used in several recent high-profile cases show that despite imperfections, improving crime scene science and training is leading to more effective prosecution.

CSI GEORGIA

A STARTLING CASE from Georgia shows just how different an animal crime scene investigation can be from a human CSI and exemplifies the kinds of techniques that can now be brought to bear. On a freezing February morning in 2010, personnel from the United Animal Nations, the Sumter Disaster Animal Response Team and the ASPCA met officers from the Washington County Sheriff's Office at a rural road lined with pine trees outside of Sandersville, approximately 130 miles southeast of Atlanta.

A short walk down a one-lane dirt path crowded with dense vegetation gave way to an open field and wooded hill that was a setting for despair. Pit bulls scattered across the field stared at the officials. Some seemed eager to greet the human visitors despite the heavy chains that tethered them to the ground. The dogs' living quarters—plastic 55-gallon drums turned on their sides—were conspicuously lacking food, and whatever water could be seen was either frozen solid or extremely dirty. Many of the dogs were puppies.

What awaited the team up the hill behind the field was more gruesome. Investigators found remains of six dogs that had been there longer than a month. They also found more than a dozen grave sites, and the vegetation over them indicated they had been used for a number of years. Although this place, to a layperson's eye, seemed to be a clear site of animal cruelty, experts had to provide detailed evidence for Georgia authorities to adequately make their case.

First and foremost, the veterinarians had to provide emergency care for each animal but administer it in a way that would not compromise the scientific and legal value of evidence of cruelty or neglect. Once triage was done, the dogs were stabilized. Experts examined the animals for physical signs of neglect—emaciation, parasites, dehydration. They also looked for evidence that the dogs were engaged in organized fighting, such as scars and new wounds caused by bites from other dogs. According to Robert Reisman, supervisor of forensic sciences at the ASPCA in New York City, who was on the scene at Sandersville, telltale injury patterns appear around the head, neck and front legs of fighting dogs. Studies have shown that the patterns in which bites appear are distinct in fighting dogs compared with two dogs that may engage in a spontaneous brawl.

Subsequently, the animals were removed to a temporary shelter set up miles away, where veterinarians would photograph them and complete physical exams. Investigators continued to photograph the crime site, map the area, take notes and video, and package evidence—all with the same meticulous care that would be used at a human crime scene. Later, veterinarians would conduct necropsies on the deceased animals to try to determine how the dogs died.

At the shelter, Reisman examined 26 dogs from the property over several days. Nearly all were emaciated, he recalls. "Even

Photograph by Grant Delin

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though we were in the South, it was very cold, and most of the dogs were shivering due to lack of adequate body weight and shelter." But to support a legal charge of animal cruelty, he had to prove that low weight was because of food being withheld rather than an underlying illness such as cancer. Veterinarians fed the animals very gradually, over days, because immediately eating huge amounts of food could shock their system. Each animal's weight was tracked; if the dogs gained weight, that would reveal that the emaciation resulted from withholding of food, not from an underlying disease that causes wasting.

Other evidence of dogfighting could have been easily overlooked by police officers without proper training, says Renee Arlt, a crime scene investigator for the Lakeland Police Department in Florida. A wood stick, rolled-up carpet and a padlock found around the Sandersville site, which might appear to be everyday items, had a whole new meaning. A trained technician would recognize that wood stick as a break stick, used to break the grip of one dog on another, and the padlock as a weight for a fighting dog's training collar.

Patterns of bloodstains on animals, and spatter around them, were also revealing. Blood samples taken on swabs from many fighting pits were sent to a geneticist for DNA analysis to ensure they were indeed from a dog and even to identify which dog. Like humans, dogs have unique DNA that can connect specific dogs to specific places. Specialists can also genetically track bloodlines from other known fighting dogs. Because many ring leaders purchase their stock from prominent breeders of fighting dogs, tracing the origins of animals can help uncover connections in a pattern of criminal activity, including conspiracy and animal abuse. DNA from fighting dogs is collected in databases, such as the Canine Combined DNA Index System at the University of California, Davis, Veterinary Genetics Laboratory.

Bloodstain analysis of an animal crime scene can differ from that of a human crime scene in various ways. A victim's stature and position at the time of injury can reveal much about what happened. For example, blood-spatter patterns on walls, floors and other surfaces can help determine how tall the assailant was and what kind of weapon was used if one takes into account that animals have some unique characteristics that challenge traditional human blood-spatter characteristics. Although animals generally stand on four legs, they may rise up on two legs to defend themselves, altering the trajectory of oozing or spraying blood in a way that an experienced investigator can interpret. And animals frequently have tails that can become saturated with blood, creating cast-off patterns of drops around a site, something not encountered for human victims.

For Nancy Bradley-Siemens, a forensic veterinarian at the

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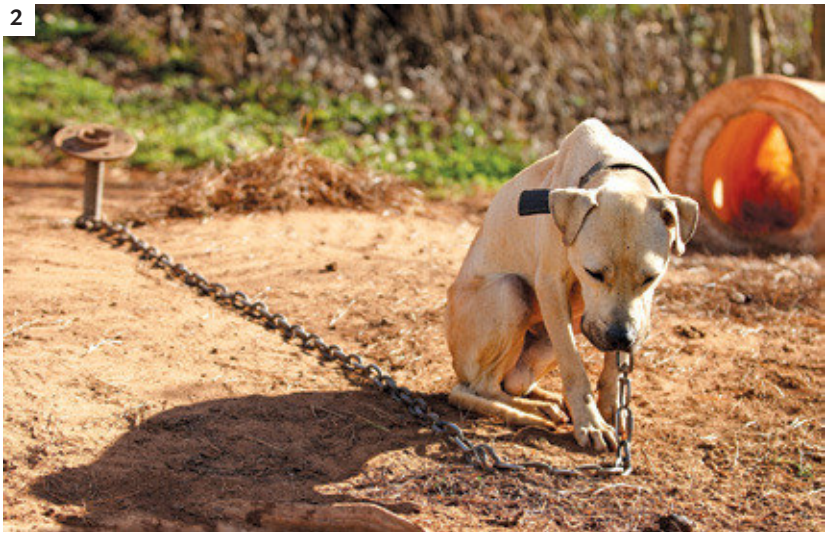

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FORENSIC SCIENTISTS excavate dog remains from a mass burial site (*1*), one of 12 graves at a Sandersville, Ga., dogfighting site. They found 26 dogs tethered with heavy chains (*2*). Jason Byrd flags evidence at the scene (*3*).

Midwestern University College of Veterinary Medicine, one blood-spatter case has stood out in her 20 years of practice—a dog that suffered such severe blunt force trauma that it had to be euthanized. The suspect claimed the dog had attacked him and that he had therefore acted in self-defense by beating it. But careful examination of the scene made it clear that the animal was actually chained to a stake in the ground near a brick fence. The suspect beat the restrained dog savagely with a shovel, then altered the scene by removing the chain and hiding the shovel. Blood spatter was found on the fence and stake, and the patterns were consistent with a blunt force beating at the level of the dog's head. Pooling of blood under the dog and on the ground further proved that the dog had been restrained, which contradicted the suspect's testimony. Faced with this evidence, the suspect finally confessed. According to Bradley-Siemens, blood analysis is not done as frequently as it could be, but to ensure that blood-spatter interpretation is accurate, more research is needed into clotting times for various species.

TIME OF DEATH

DETERMINING WHEN animals at a crime scene died is also important, for example, in revealing whether a suspect could have been present at the time of the abuse. In some circumstances, pinpointing time of death can be done with altered human CSI techniques, but in other cases new methods are being applied. Here, too, techniques devised by veterinary CSI research have helped attain convictions.

Some of the best clues can be derived from insects crawling around a dead body. As entomologists do with human remains, in animal cases they examine the various stages of insect development. But the time it takes certain insects to set up residence in a corpse may differ among species and is distinct from humans. And larvae that pupate on animals with long, thick coats may stay there after feeding on them instead of wandering away, as they often do with humans.

At the Sandersville dogfighting scene, one burial pit contained multiple animals. Decomposition happens faster at the ground's surface, so remains on the top of the pit were largely skeletal, with limited or no insect infestation. Bodies farther down had multiple insects at different stages of colonization, which helped entomologists determine approximate times of death. Various stages of maggot development, for example, provided evidence on how long dogs had been buried.

The analysis of remains at Sandersville, along with physical evidence from the live dogs, indicated injuries consistent with organized dogfighting, along with severe neglect, including starvation. Even at various stages of decomposition, it was possible to see scar patterns that are consistent with organized fighting. The forensics work formed the basis for animal cruelty charges brought by the office of Hayward Altman, district attorney at the Middle Judicial Circuit of Georgia. Several ASPCA experts provided critical testimony about conditions they witnessed at the scene. At the end of a three-day trial, Derrick Montez Daniels of DeKalb County, Georgia, and Billy Taylor, Jr., of Sandersville were convicted on 26 misdemeanor counts of animal cruelty. Daniels was sentenced to five years in state pris-

on and five years of probation, and Taylor was sentenced to one year in county jail and nine years of probation.

VICTIM of a dog-fighting operation in Sandersville is examined by forensics experts for emaciation, dehydration and parasites.

UNIQUE CHALLENGES

ANOTHER CHALLENGE that forensic veterinarians are meeting is the inability to ask animals what happened to them. Body language can be revealing. Trained veterinarians can assess if an animal is in pain by observing its behavior, appearance, mobility, and response to handling and analgesics. A rooster, Touroo notes, may be "extremely quiet and unresponsive, hang its head low and may breathe more deeply if it's in pain. A judge and jury can look at a video of a rooster that is clearly suffering and may not pick up on these signs" without guidance from an expert.

Investigators may also have to cope when victims inadvertently destroy evidence, as they do routinely. Touroo worked on a dog-shooting case in which the animal hid for days, licking its wounds. "This made it extremely difficult to determine which was the entry wound and which was the exit wound," she says. Touroo and a local medical examiner used radiographs to assess bone and flesh under the damaged layers of skin and determined the direction the bullet took, which told them the dog was facing away from its shooter, countering the shooter's claim that the dog was attacking him when he fired.

More hurdles arise during necropsy. For example, very few studies have been done on trauma and human hair, let alone animal hair, coats or fur. One recent study of human hair noted, however, that strands appear microscopically different when cut by a knife or scissors. In 2012 an Alabamian pug named Bama was found in horrific condition—apparently skinned alive by what many assumed was a human assailant. But hair and wound analysis by Touroo validated that Bama was attacked by another animal. Researchers also think they can get more information as they figure out how to better use necropsies to reveal the impacts of different weapons, as well as injuries associated with specific kinds of abuse. For example, in Reisman's experience, skull, rib and femur fractures are common in intentional physical abuse cases and not in motor vehicle accidents. Continuing to build this body of research will make it easier for forensic veterinarians to definitively assess the cause of injuries.

DECIPHERING DNA

AS USEFUL AS EVIDENCE found at a crime scene can be, sometimes more is needed to clinch a case—namely, genetic analysis and other lab tests. Some valuable tools in human crimes—such as DNA analysis—are still fairly rare for animal crimes, but progress has been made.

Reisman was the forensic veterinarian on two cases in the late 2000s that for the first time in New York City used DNA to win a cruelty conviction. In one instance, a four-year-old cat named Madea in Brooklyn had been savagely beaten to the point that she had to be euthanized. While searching the scene, a detective found an umbrella in a hard plastic case. When Reisman examined it, he found punctures and scratches consistent with cat bites, along with DNA. He matched the cat saliva on the umbrella to DNA from Madea's tissue sample, tying that weapon to the victim. That finding, combined with testimony, led to a guilty verdict for aggravated cruelty and criminal mischief.

Use of RNA to help determine an animal's time of death is emerging as well. RNA is relatively stable over time, and it degrades at a predictable pace. By knowing the extent of RNA degradation, one can extrapolate backward and develop a reasonably accurate time of death. Nanny Wenzlow, who recently completed a forensic veterinary pathology fellowship at the University of Florida, is pioneering this work with horse tissue. She developed algorithms for RNA breakdown in the brain, muscle and liver after death—which occurs at different rates—to help establish a time of death. That could confirm or refute a suspect's alibi, Wenzlow notes.

STOP THE VIOLENCE

ALTHOUGH VETERINARY FORENSIC SCIENCE has had many successes, much more research is needed. "This is such a novel area, and we are still far behind human clinical and pathological forensic medicine," the ASPCA's Touroo says. More investigators trained in animal crime scene investigation are needed, too. When Reisman started working for the ASPCA in 1988, forensic veterinary medicine was not even a recognized discipline. Many of the materials used today arose through trial and error in Reisman's work. He eventually helped form the International Veterinary Forensic Sciences Association, which now boasts nearly 130 members from 16 countries.

The only university program in the U.S. that offers a comprehensive curriculum and dedicated research is the ASPCA

SCIENTIFIC AMERICAN ONLINE For a podcast about the origins of forensic science, go to ScientificAmerican.com/jan2017/byrd

DOG COLLAR can become so tight that skin grows around it. Laura Niestat holds photographs of one case, in front of a canine skeleton being inspected for trauma.

BEBETO MATTHEWS *AP Photo*

Of course, animal abuse is terrible. But pursuit of cruelty cases is becoming even more frequent because, put bluntly, individuals who abuse animals often abuse people.

Veterinary Forensic Sciences Program at the University of Florida, where one of us (Byrd) is director of education and where Touroo and others teach. Its master of science degree trains veterinarians to correctly gather evidence and prepares them for appearing in court as an expert witness.

Students and faculty in the program are conducting research to advance the field. For example, they are establishing how to better estimate the sex of a dog from its skull, something that is done with fairly good reliability in humans. They are also working on specifying common scar and wound patterns on fighting dogs. And by partnering with Tufts University, they have shown, as noted earlier, that dogs and cats sustain different types of injuries when hit by a car than when attacked intentionally with blunt force by a person. That study could help forensic veterinarians prove intentional cruelty masked as an accident.

Reisman, for his part, is helping the NYPD and the ASPCA to build a database of cases in New York, listing such information as whether abuse took the form of neglect or aggression, the nature of injuries and the time period over which they occurred, whether domestic violence or child abuse had also been found, and the species, breed, age and gender of animals affected. He hopes that over time, this database will help the agencies gain more insight into animal victims and their attackers by unearthing patterns. For example, do injuries look different when the perpetrator is a man, woman or child? Or, in cases of domestic violence, how often is the animal killed? Experts also hope that raising the skill level of police, animal-control officers and other professionals will lead to more effective trials and convictions, stricter sentencing requirements and therefore an overall decrease in animal cruelty. Regular workshops are held through the University of Florida, and experts such as Reisman, Touroo and others hold trainings across the country.

Improvements in veterinary crime science could help human victims, too. A 1998 study in the *Journal of Emotional Abuse* found that 71 percent of women in domestic violence shelters reported their batterer abused or killed their animals or threatened to do so. In 2007 research in the *Journal of Interpersonal Violence* showed that "batterers who also abuse their pets are both more controlling and use more dangerous forms of violence than batterers who do not." Attorney Diane Balkin of the Animal Legal Defense Fund adds, "Violence is violence, regardless of whether the victim has two or four legs. Early intervention with a child or teenager who abuses an animal may prevent that individual from harming another animal or from harming a human and may provide that individual with much needed evaluation and treatment."

Randall Lockwood, senior vice president for forensic sciences and anticruelty projects at the ASPCA, concurs: "I know there are animals, women, children and elders that are alive today that likely would not have been" if prosecutors had not brought violent individuals to justice. Veterinary forensic science, he says, "gives the victims a voice." SA

MORE TO EXPLORE

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ASPCA Veterinary Forensic Sciences Program, University of Florida: **http://forensics.med.ufl.edu**

National Link Coalition, a resource on the connections between violence against humans and animals: **http://nationallinkcoalition.org**

FROM OUR ARCHIVES

When DNA Implicates the Innocent. Peter Andrey Smith; Advances, June 2016.

scientificamerican.com/magazine/sa

WARRIOR

Richard Schiffman is an environmental journalist based in New York City.

Q&A

Paleontologist-turned-politician Richard Leakey leads the charge in Kenya's war on poaching

By Richard Schiffman

On April 30, 2016, President Uhuru Kenyatta of Kenya set fire to the country's stockpile of confiscated elephant ivory and rhinoceros horn. It was the largest event of its kind—105 tons of ivory worth about $100 million and 1.3 tons of horn worth $67 million went up in flames. In a way, the burn was a funeral for the more than 6,000 elephants and over 300 rhinoceroses that were poached for the contraband. More important, it was a smoke signal to convey that these materials are worthless unless they are on the animals themselves, which attract tourists and play key roles in keeping ecosystems healthy.

Tusk by tusk, horn by horn, Africa is losing its iconic wildlife. Africa's elephants have plummeted by 62 percent in the past decade alone, mostly as a result of poaching, and only 29,000 rhinos remain, down from 70,000 in 1970. They are hardly the only victims. Lion populations have dropped 43 percent during the past two decades; giraffes, which numbered 140,000 in 1999, have declined to 80,000 individuals—the list goes on and on.

To stem the destruction, Kenyatta made Richard Leakey chair of the Kenya Wildlife Service (KWS) in April 2015. This is not Leakey's first time with the KWS. In 1989 he was appointed to head the then fledgling wildlife service. Up to that point he was best known for his discoveries of human fossils, but he soon developed a reputation as an incorruptible and confrontational public servant. He resigned in 1994, alleging corruption among officials in the government of President Daniel arap Moi.

Now the conservation stakes are even higher. Elephants, rhinos and other species are facing more intense poaching pressure than ever before from organized criminal gangs that are racing to meet Asia's burgeoning demand for wildlife products. Scientific American interviewed Leakey, now 72, at Stony Brook University on Long Island, where he is chair of the Turkana Basin Institute, about his efforts to preserve Kenya's wild heritage. The interview has been edited for clarity. —The Editors

Illustration by Tracie Ching

SCIENTIFIC AMERICAN: Why did you, as the heir of the great family of paleontology, go into conservation?

RICHARD LEAKEY: When I studied fossils, I was dealing with species that became extinct because of climate change, because of overpredation. Today when I stand on the magnificent Kenyan landscape in the midst of so many of their successors, the survivors—now different species—it's a very powerful experience. I feel I'm at home with them. I understand myself better. I sense my place within the larger continuum of life. So the paleontology is not separate from my concern for wildlife—it is very much a part of it.

As head of the Kenya Wildlife Service from 1989 to 1994, you famously cracked down on corruption in the wildlife service and armed your rangers to combat a wave of ivory poaching, which was hitting Kenya hard at the time.

We also had to somehow impact the market. My idea was to destroy confiscated ivory by bonfire. That generated massive publicity around the fact that elephants were being killed for their teeth, which led to CITES [the Convention on International Trade in Endangered Species] putting an international ban on ivory sales. The ban had a big impact. The number of elephants being killed in Kenya went down from thousands a year to maybe 100 by the end of 1990, and it remained at that low level for at least a decade.

What happened to bring poaching back to the disastrous levels that exist today in much of Africa?

Once the illegal killing subsided, there was still a lot of ivory sitting around in storerooms, and some countries—South Africa in particular, Botswana, Namibia, Zimbabwe—thought that this could earn them money if it was sold. They persuaded CITES to allow them to put it on the market. We in Kenya felt that once the ivory trade got going again, it would be very difficult for people to distinguish between a valid export document and a false one. So, very quickly, ivory was again being poached and exported out with doctored documents. The price rose sharply, and big criminal cartels started taking an interest. It was a deplorable situation.

To help deal with this crisis, you were invited back last year to chair the KWS.

UP IN FLAMES: A wildlife ranger looks on as pyres of confiscated elephant tusks burn in Nairobi National Park on April 30, 2016.

CARL DE SOUZA Getty Images

Why did you accept the position?

The president promised that the board and I would have a lot of freedom to make decisions that won't be interfered with politically by corrupt officials. When I started as chairman, morale in the wildlife service was abysmal. Now we're beginning to see the right people doing the right things because they feel safe; they're not going to be interfered with. In the past 11 months, Kenya has lost 94 elephants—in contrast to several hundred for the same period the previous year. We've revised Kenya's Wildlife Act to streamline management of the wildlife services, hire 1,000 additional rangers and toughen penalties for poaching. We are now recruiting and training a body of special wildlife prosecutors. We're getting new cars for our staff, fixing the roads, giving our people decent housing in the bush, providing health care and getting new equipment to tackle the poaching.

To protect wildlife, you also need buy-in from the local communities. How are you engaging them?

Over the past decades National Geographic, the BBC, all these big media groups have been producing documentaries on African wildlife for consumption abroad. None of these films has been shown in Kenya—ever. WildlifeDirect, a charitable organization that I founded, persuaded some film houses to give us these documentaries for free. Since January 2016 they have been airing every Saturday at 8 P.M. They are trending number one in Kenyan social media every time they are shown. WildlifeDirect also produces *NTV Wild Talk,* which airs on Tuesday nights. These are the first films Africans themselves have made about wildlife. You'll soon have a population in Kenya that is as much in love with these animals as people are in London, Paris and New York.

The usual rationale for game reserves in Africa is that they generate tourist dollars. Is that the KWS's rationale?

Kenyans are recognizing that the whole philosophy around wildlife has got to change. For now tourism is a major element in our economic future. It is fickle, however, and at best a medium-term help because industries will eventually take up the slack as the nation develops. But on another level, many people are coming to recognize that wild spaces where you can take a deep breath and enjoy beauty is something that every country needs. Kenyans are seeing this as their invalu-

SCIENTIFIC AMERICAN ONLINE Learn more about wildlife crime at ScientificAmerican.com/jan2017/leakey

able national heritage. That is far more important than tourism in the long term.

What about people in rural villages who live dangerously close to wild animals?
Kenya's human population has tripled. People are increasingly moving into areas where animals are. A lot get killed by elephant, buffalo, crocodile; crops are destroyed, and there is a certain sour feeling between humans and animals. I firmly believe that we have to fence off the national parks so that the animals cannot get into the farms and the goats and cattle of the herders can't get into the parks.

That's a pretty radical proposal.
Yes, but it may be the only one that works. The technology for fencing is very good now but expensive. We're going for concessional loans, which have low-interest rates that can be paid back in installments over 30 years, from multinational institutions like the World Bank. These fences will make it easier to deal with the poaching problem because herders' stock wandering around parks are frequent covers for poachers who pretend to be herders. It is going to take us three to five years, but when we get to the other side people will say, "Well done." At the moment they're saying, "You're crazy."

People in rural Kenya are mostly not seeing much of a payback from wildlife tourism. In Namibia and Botswana, community-run reserves have garnered local support. Don't you need to get average Kenyans behind the protection of wildlife?
Of course, you need to get people's support, but do you do it on the basis that when you've got a boom in tourism, the people living around the parks get a bonus and their kids go to school and then when tourism wanes, unfortunately, their kids are pulled from school? In my view, money from tourism should go to the central government and be used to build better hospitals, roads and infrastructure for the whole nation. It is not just for temporarily propping up the people who happen to live next to the park.

Do you feel a conflict about using government funds to protect wildlife when so many Kenyans are impoverished?
When I was secretary to the cabinet in Kenya, every budgeted item crossed my desk for the entire machinery of government. And many of my colleagues from my former life in wildlife said, "Couldn't you just add a little bit to our budget? It would be such a help." And I would have to tell them, "Morally, no. When you've got so many people whose children don't go to school, without inoculations, without water, without homes even, no, I can't take any extra money from them to give to you for wildlife conservation." That was a tough two years for me.

Now the shoe is on the other foot again.
Yes, but I appreciate how much it matters to help the people. Without tackling poverty, there is no security for anybody in our society, no institutional security, no national security—and definitely no security for our wild lands and wildlife. The national parks are there for the good of everyone. The money generated by them should be used to help all Kenyans get a better education, have better roads and infrastructure, and live longer, healthier lives.

Mombasa, Kenya's second-largest city, remains perhaps the leading port in East Africa for the export of illicit ivory to Asia. What is the Kenyan government doing to get this situation under control?
Nowadays most of the ivory that has been going through Mombasa is not Kenyan—it's Tanzanian; it's from Central Africa. The first objective I gave myself was to stop the killing of Kenyan elephants, and we have done that. Stopping the smuggling is beyond the scope of the KWS. It remains a work in progress. The Port Authority in Mombasa recently cleaned out their staff from top to bottom. They've got a completely new customs unit, a new unit for handling containers, a new unit on the dock. At the moment, it's looking good.

A proposed highway would cut across the Serengeti Plain in neighboring Tanzania. Some environmentalists say this would end the largest wildlife migration on earth. Yet you are in favor of it.
The Serengeti is a fantastic ecosystem and should be preserved at all costs, but we need to address the problem realistically. The Serengeti is also surrounded by growing communities. The towns this road is intended to serve are projected to grow into a three-million-plus metropolis. Tanzania is building a second port within the next decade. They are clearly looking—as we in Kenya are—at trade with Central Africa. Hence, the need for a road. So yes, I support a transport corridor across the Serengeti. But 40 kilometers of the highway should be elevated 30 meters above the ground to enable wildlife to move back and forth.

What is your greatest worry?
Climate change. It's just terrifying. I'm really concerned that through population growth and unplanned development around the parks, we've created "islands" for the wildlife. And if you look at the paleontological record, where there are islands and there has been climate change the island species become extinct long before they do on the mainland because there is nowhere to go. If there is a drought and the waterholes dry up in the park, there is nowhere to go. I'm not sure what we are going to do about lack of water and diminished rainfall in the future.

Brad Pitt will be playing you in a movie about your life. How do you feel about that?
I always wanted there to be a film where the plight of elephants and rhinos could be exposed. If Brad Pitt is seen fighting to save these animals, tens of millions of people, including in China, will believe him.

So Brad Pitt playing Richard Leakey could be a more powerful voice than Richard Leakey.
A thousand times more powerful! SA

MORE TO EXPLORE

Wildlife Wars: My Fight to Save Africa's Natural Treasures. Richard Leakey and Virginia Morell. St. Martin's Press, 2001.

Wildlife Protection and Trafficking Assessment in Kenya: Drivers and Trends of Transnational Wildlife Crime in Kenya and Its Role as a Transit Point for Trafficked Species in East Africa. Sam Weru. TRAFFIC Report, May 2016.

FROM OUR ARCHIVES

The Ivory Trail. Samuel K. Wasser, Bill Clark and Cathy Laurie; July 2009.

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RECOMMENDED

By Clara Moskowitz

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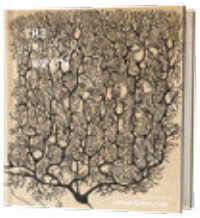
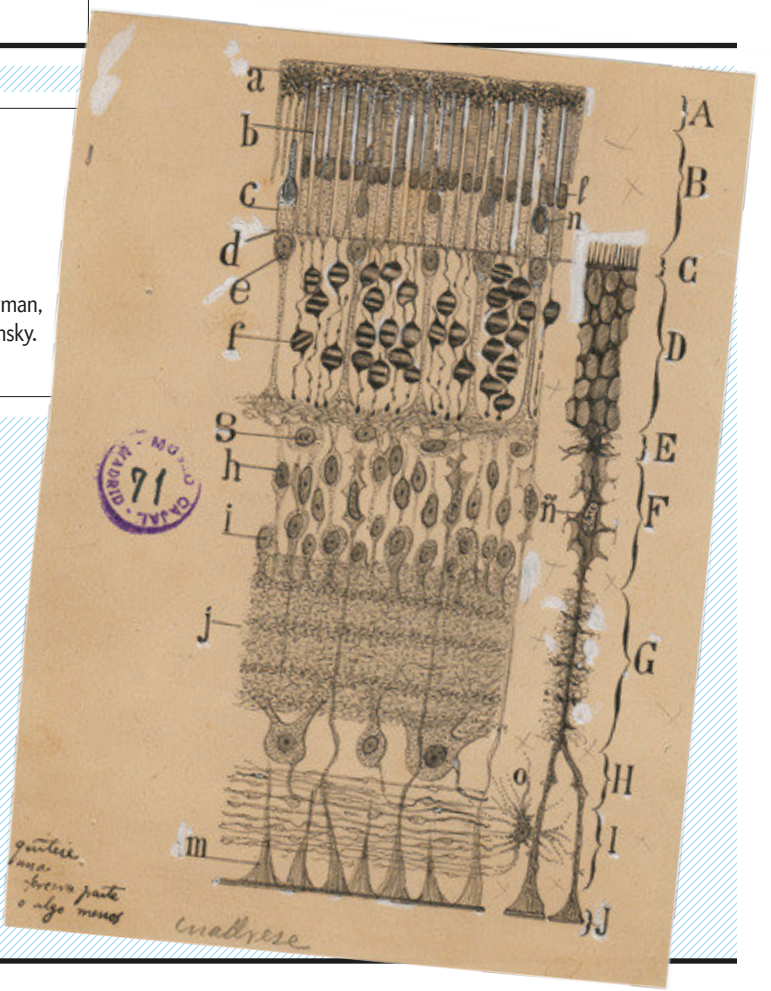


The Beautiful Brain:
The Drawings of Santiago Ramón y Cajal

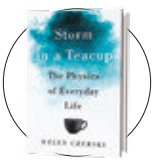
by Larry W. Swanson, Eric A. Newman, Alfonso Araque and Janet M. Dubinsky. Abrams, 2017 ($40)

Often called the "father of modern neuroscience," Santiago Ramón y Cajal was a Spanish scientist whose exquisitely detailed drawings helped to reveal the pathways, cells and structure of the brain. Born in 1852, Cajal crafted illustrations, based on painstaking observations of brain slices under the microscope, that led to major discoveries long before neuroimaging was possible. He realized, for instance, that the brain was a vast network of individual neurons—a finding that led him to earn a Nobel Prize in 1906. In this large-format book, 82 of Cajal's drawings are paired with commentary and essays from neuroscientists celebrating both the scientific value and the pure artistry of his work.



CAJAL'S DRAWING of classes of cells in the retina of the eye.

Storm in a Teacup:
The Physics of Everyday Life



by Helen Czerski. W. W. Norton, 2017 ($26.95)

In an age when any questions we have about the workings of the world are instantly answerable via Google, physicist Czerski pushes us to resist the search engine. Instead of looking up easy explanations, she says, why not learn some simple physics so that you can try to puzzle things out for yourself? Her book provides that knowledge and puts it to work, showing how the laws of physics account for daily phenomena such as why frying food makes it crispy, why drying clothes in damp weather is impossible and why you get electric shocks more often after it snows. "Knowing about some basic bits of physics turns the world into a toybox," she writes, full of marvels that become more interesting the more we understand them. "A toaster can teach you about some of the most fundamental laws of physics, and the benefit of a toaster is that you've probably got one, and you can see it working for yourself."

Language at the Speed of Sight:
How We Read, Why So Many Can't, and What Can Be Done about It

by Mark Seidenberg. Basic Books, 2017 ($28.99)

In recent decades scientists have gained "remarkable consensus" on how our brain learns to read, writes neuroscientist Seidenberg. Then why, he asks, are U.S. literacy levels so low? Poverty and screen usage are big factors, but the way we teach reading is also a major part of the problem, he argues: "Very little of what we've learned about reading as scientists has had any impact on what happens in schools." For instance, a popular strategy taught to kids who struggle to read a word suggests various guessing strategies, such as thinking of what word might fit in the sentence or looking at illustrations. But these tactics actually distract kids from learning the skills needed to phonetically decode unfamiliar words. Seidenberg reviews the latest science on reading and makes an impassioned plea for putting this knowledge to use.

Earth in Human Hands:
Shaping Our Planet's Future

by David Grinspoon. Grand Central Publishing, 2016 ($28)

In this overview of the "Anthropocene," the proposed name for our current geologic epoch, astrobiologist Grinspoon describes how humans are disrupting global ecosystems and places our present situation into a broader cosmic perspective. In flavorful prose, he dives deep into the history of life on Earth (and beyond) and muses on ways that geoengineering, interplanetary colonization or contact with galactic civilizations could define this human-dominated epoch just as much as climate change, overpopulation and resource scarcity. "It took 4.5 billion years for Earth to go from dead rock to space walk, from molten ball to shopping mall, from sea to me, from goo to you," he writes. What comes next? This hybrid of a meditative memoir, a scientific primer and a call to arms presents possible answers. *—Lee Billings*

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

When Facts Backfire

Why worldview threats undermine evidence

By Michael Shermer

Have you ever noticed that when you present people with facts that are contrary to their deepest held beliefs they always change their minds? Me neither. In fact, people seem to double down on their beliefs in the teeth of overwhelming evidence against them. The reason is related to the worldview perceived to be under threat by the conflicting data.

Creationists, for example, dispute the evidence for evolution in fossils and DNA because they are concerned about secular forces encroaching on religious faith. Anti-vaxxers distrust big pharma and think that money corrupts medicine, which leads them to believe that vaccines cause autism despite the inconvenient truth that the one and only study claiming such a link was retracted and its lead author accused of fraud. The 9/11 truthers focus on minutiae like the melting point of steel in the World Trade Center buildings that caused their collapse because they think the government lies and conducts "false flag" operations to create a New World Order. Climate deniers study tree rings, ice cores and the ppm of greenhouse gases because they are passionate about freedom, especially that of markets and industries to operate unencumbered by restrictive government regulations. Obama birthers desperately dissected the president's long-form birth certificate in search of fraud because they believe that the nation's first African-American president is a socialist bent on destroying the country.

In these examples, proponents' deepest held worldviews were perceived to be threatened by skeptics, making facts the enemy to be slayed. This power of belief over evidence is the result of two factors: cognitive dissonance and the backfire effect. In the classic 1956 book *When Prophecy Fails,* psychologist Leon Festinger and his co-authors described what happened to a UFO cult when the mother ship failed to arrive at the appointed time. Instead of admitting error, "members of the group sought frantically to convince the world of their beliefs," and they made "a series of desperate attempts to erase their rankling dissonance by making prediction after prediction in the hope that one would come true." Festinger called this cognitive dissonance, or the uncomfortable tension that comes from holding two conflicting thoughts simultaneously.

Two social psychologists, Carol Tavris and Elliot Aronson (a former student of Festinger), in their 2007 book *Mistakes Were Made (But Not by Me)* document thousands of experiments demonstrating how people spin-doctor facts to fit preconceived beliefs to reduce dissonance. Their metaphor of the "pyramid of choice" places two individuals side by side at the apex of the pyramid and shows how quickly they diverge and end up at the bottom opposite corners of the base as they each stake out a position to defend.

In a series of experiments by Dartmouth College professor Brendan Nyhan and University of Exeter professor Jason Reifler, the researchers identify a related factor they call the backfire effect "in which corrections actually *increase* misperceptions among the group in question." Why? "Because it threatens their worldview or self-concept." For example, subjects were given fake newspaper articles that confirmed widespread misconceptions, such as that there were weapons of mass destruction in Iraq. When subjects were then given a corrective article that WMD were never found, liberals who opposed the war accepted the new article and rejected the old, whereas conservatives who supported the war did the opposite … and more: they reported being even *more* convinced there were WMD after the correction, arguing that this only proved that Saddam Hussein hid or destroyed them. In fact, Nyhan and Reifler note, among many conservatives "the belief that Iraq possessed WMD immediately before the U.S. invasion persisted long after the Bush administration itself concluded otherwise."

If corrective facts only make matters worse, what can we do to convince people of the error of their beliefs? From my experience, **1** keep emotions out of the exchange, **2** discuss, don't attack (no ad hominem and no ad Hitlerum), **3** listen carefully and

try to articulate the other position accurately, **4** show respect, **5** acknowledge that you understand why someone might hold that opinion, and **6** try to show how changing facts does not necessarily mean changing worldviews. These strategies may not always work to change people's minds, but now that the nation has just been put through a political fact-check wringer, they may help reduce unnecessary divisiveness. SA

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Illustration by Izhar Cohen

Data Deliver in the Clutch

Where does the shortstop play in a paradigm shift?

By Steve Mirsky

Let's hear from the two Toms.

"A long habit of not thinking a thing wrong," wrote Tom 1, "gives it a superficial appearance of being right, and raises at first a formidable outcry in defense of custom. But the tumult soon subsides. Time makes more converts than reason."

Almost two centuries later Tom 2 stated that his "most fundamental objective is to urge a change in the perception and evaluation of familiar data."

Thomas Paine in his 1776 pamphlet *Common Sense* was advocating for the independence of the American colonies from Great Britain. Thomas Kuhn in his 1962 book *The Structure of Scientific Revolutions* was describing how science moves along within a framework until anomalies require what has become a cliché term for a change in outlook: a paradigm shift.

That both these Toms and their seminal insights are cited by sportscaster Brian Kenny in his new volume *Ahead of the Curve* tells you that this ain't your grandparents' baseball book. Unless one grandparent was the visionary baseball executive Branch Rickey.

But fear not, gentle reader, as columnists of Rickey's era sometimes said. I'm not going to explicate baseball's newfangled statistics, such as OPS, BABIP and WAR. (That's done dandily in Kenny's book if you're interested.) Instead I want to talk about Kenny's description of information availability and decision making in baseball as a microcosm of the larger problem that a wide array of human enterprises face: insisting on remaining stupid when becoming smarter is an option.

Branch Rickey is mostly remembered today for bringing in Jackie Robinson to play for the Brooklyn Dodgers in 1947. But Rickey also published an article in *Life* magazine in 1954 about the need for more meaningful statistics. And yet another half a century passed before teams really started to apply this information. (No defensive shifts until the paradigm shift.)

Why the long wait? Kenny quotes Nobel economist Daniel Kahneman (it's not even your parents' baseball book) on the subject of entrenched idiocy. Kahneman said that "people can maintain an unshakable faith in any proposition, however absurd, when they are sustained by a community of like-minded believers."

And then there's Bill James, the former pork-and-bean cannery security guard who, in his groundbreaking writings, spelled out the truth of the value of deep analytical insight in baseball in terms so plain and firm as to finally command the assent of even some baseball people. "People horribly overestimate the extent to which they understand the world," Kenny quotes James. "The world is billions of times more complicated than any of us understand, and because we are desperate to understand the world, we buy into these explanations that give us the illusion of understanding."

Which brings us to our newly elected president. A better-informed electorate would have been deeply troubled by Mr. Trump's outrageous statement in March 2016 that the owners of the Chicago Cubs were doing a "rotten job." In fact, the team's trajectory had been steeply upward over the four previous years—the direct result of bringing in new thinkers well versed in modern baseball's scientific analysis. In November, of course, the Cubs finally broke their 108-year-long World Series championship drought.

So how was such an obviously misinformed Mr. Trump able to maintain his large fan base of "like-minded believers"? A clue can be found in the actions of some of them after the first presidential debate. A few Donald devotees disliked newscaster Lester Holt's performance as moderator. So they tweeted nasty comments at Cubs pitcher Jon Lester. Yes, these jesters chose to pester any Lester rather than to simply fester.

Rickey ended his *Life* article: "It is the hardest thing in the world to get big league baseball to change anything. But they will accept this new interpretation of baseball statistics eventually. They have to." Because at Wrigley Field or in any field, remaining willfully ignorant just isn't a viable, long-term strategy. SA

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.

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Illustration by Matt Collins

50, 100 & 150 YEARS AGO

INNOVATION AND DISCOVERY AS CHRONICLED IN *SCIENTIFIC AMERICAN*

Compiled by Daniel C. Schlenoff

JANUARY

1967 Lie-Detecting Hucksters

"In the past few years both the methods of 'lie detection' and the polygraph itself have been subjected to increasingly critical scrutiny. Although the polygraph was developed as an aid in police work, enterprising practitioners have long since discovered new applications for the device, and since about 1950 the polygraph has become firmly established in industry and government. There are some 500 commercial polygraph firms. Many companies retain polygraph examiners not only to investigate specific losses but also to conduct routine preemployment interviews in an attempt to identify applicants with a criminal record, alcoholics, homosexuals or people who are likely to be disloyal to the company. Outside the Federal Government the polygraph remains largely uncontrolled. So far only Illinois, Kentucky and New Mexico have adopted legislation requiring polygraph operators to be licensed."

Asphalt Agriculture

"Petroleum products are being used in an ingenious effort to upgrade submarginal land. In Libya the Esso Research and Engineering Company undertook in 1961 to stabilize 125 acres of shifting sand dunes by spraying them with a low-grade oil. Such dunes usually cannot support even vegetation that will grow in the desert, but the company announced that 80 percent of the eucalyptus and acacia seedlings it had planted on the dunes had survived and are now trees averaging 25 feet in height. The Libyan government has contracted for the stabilization of 3,000 additional acres, an action that could eventually lead to the creation of a national forest in the treeless desert kingdom."

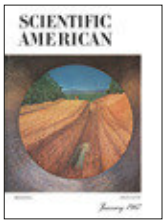
1917 Attention Span

"Why is it that motion pictures are so popular? Why are they able to compete side by side with our best plays? It is difficult indeed to hold the interest of a metropolitan audience through three acts of a drama when the plot can be anticipated in the first act. Modernism calls for abbreviated action; and photoplays are stories told more or less in synopsis form. The plot is unfolded in the least possible time. Thus, if a stage play requires three hours, in the photoplay it is pictorially told in one hour, and just as effectively. The only exception is to be found in those plays that depend for their success on clever volleys of dialogue."

Motor Vehicles

"In the year just closed, the U.S. has produced more automobiles, both passenger carrying and commercial vehicle types, than have ever before been made in the same period. The development of the automobile mechanism has reached that point where the majority of automobiles incorporate the same essential principles. It matters not whether the engine is one of four or twelve cylinders or the selling price of the car $500 or $5,000, the proportions of the constituent parts and the best materials for the different members are now so well known that engine or chassis failure, resulting from poor design, is practically unknown on even the cheapest cars."

For archive images of motor vehicles from 1917, see www.ScientificAmerican.com/jan2017/motors



1967

1917

1867

1917: Scoring saws slice up cakes of frozen lake ice for private or commercial consumption.

Harvesting Ice

"A large part of the ice consumed yearly in this country has its origin miles or hundreds of miles away, on the surface of some quiet lake. During the winter the ice harvest furnishes employment to a large army of men; and if the cold weather brings to a complete halt many industries and occupations in the rural districts of our northern States, it is equally true that the ice harvest offers lucrative employment to those desirous of work [*see illustration*]."

1867 The Epoch of Tunnels

"Tunneling on railroads is being pushed to an extreme. Even where a detour would avoid a bore, engineers seem to have a peculiar gratification in piercing the earth. Apart from the pride of a great work completed, is it not possible that the fascination of delving after the mysterious and unknown may be a clue to the present rage for tunneling? We tunnel under lakes for water, through mountains for roads intended to save time and distance, and even propose to unite countries, severed by seas, with tunnels. This age may be called the age of the earth-borers."

SCIENTIFIC AMERICAN, VOL. CXVI, NO. 3; JANUARY 20, 1917

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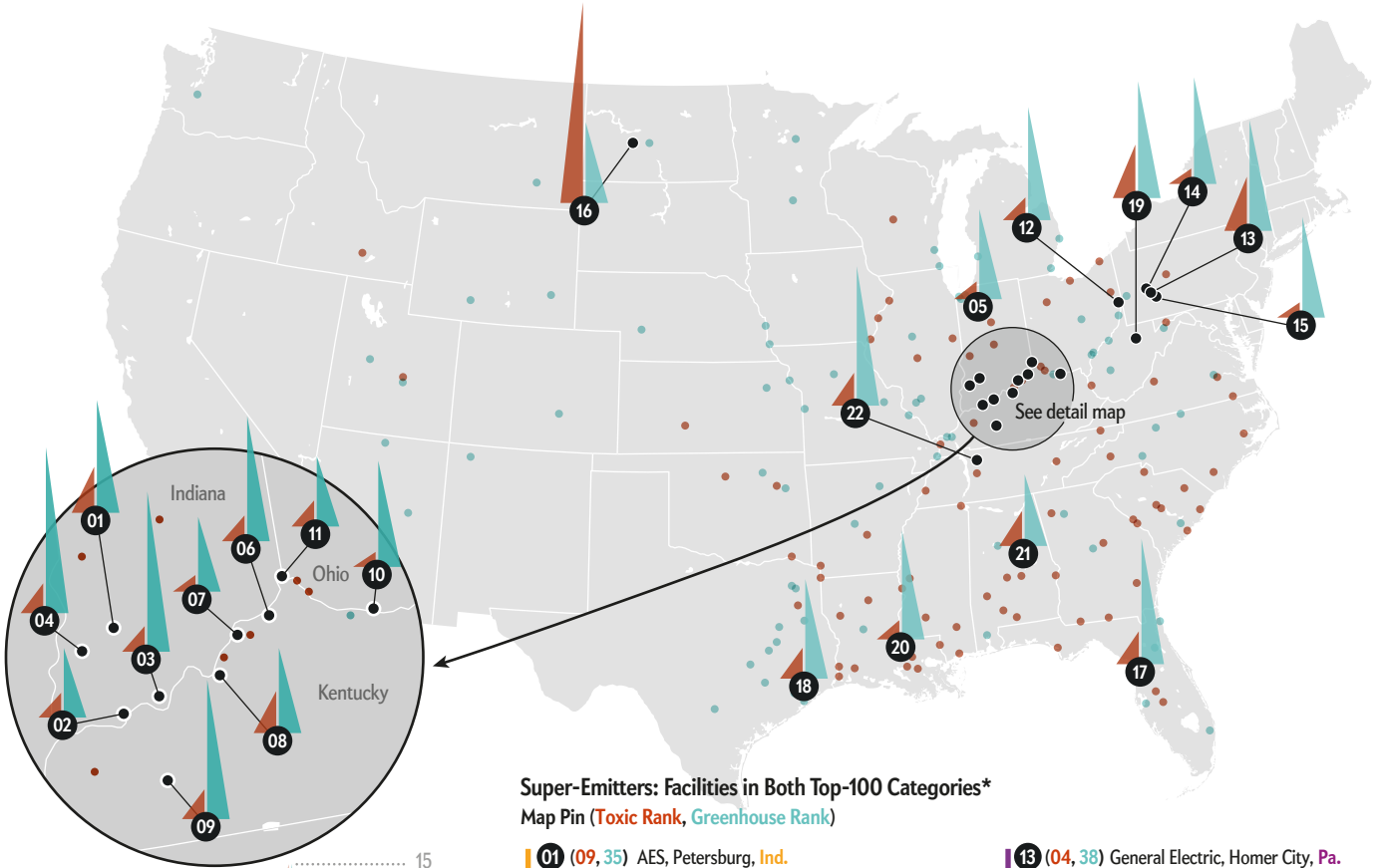
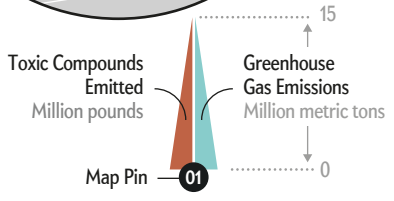
Top Air Polluters

A small number of industrial facilities emit an enormous share of toxics and greenhouse gases

A mere 100 facilities, out of 20,000, produced one third of U.S. industry's toxic air pollution in 2014. Another 100 released one third of industry's greenhouse gas emissions, among 7,000 installations that discharge the gas. And according to an investigation by the Center for Public Integrity that created the rankings, 22 "super-polluter" sites appeared on both lists (*noted below*). Many are coal-fired power plants, and some rank high because they are very large. This group is responsible for a significant chunk of U.S. industrial air pollution. (Since 2014 eight of the 178 facilities have closed, but none were super-polluters.) Researchers at the center also used census data to show that most of the 100 facilities on the toxics list are located in poor neighborhoods—where incomes are lower than the national average. The good news is that cleaning up the sites could make a big dent in toxic compounds that are implicated in respiratory illnesses and in the country's contribution to climate change. The researchers say that existing regulations are sufficient, but weak enforcement must improve. *—Mark Fischetti*





- Industrial Top-100 Toxic Compound Emitters
  270 million pounds total (2014)
- Industrial Top-100 Greenhouse Gas Emitters
  More than one billion metric tons total (2014)
- Super-Emitter

Super-Emitters: Facilities in Both Top-100 Categories*

Map Pin (Toxic Rank, Greenhouse Rank)

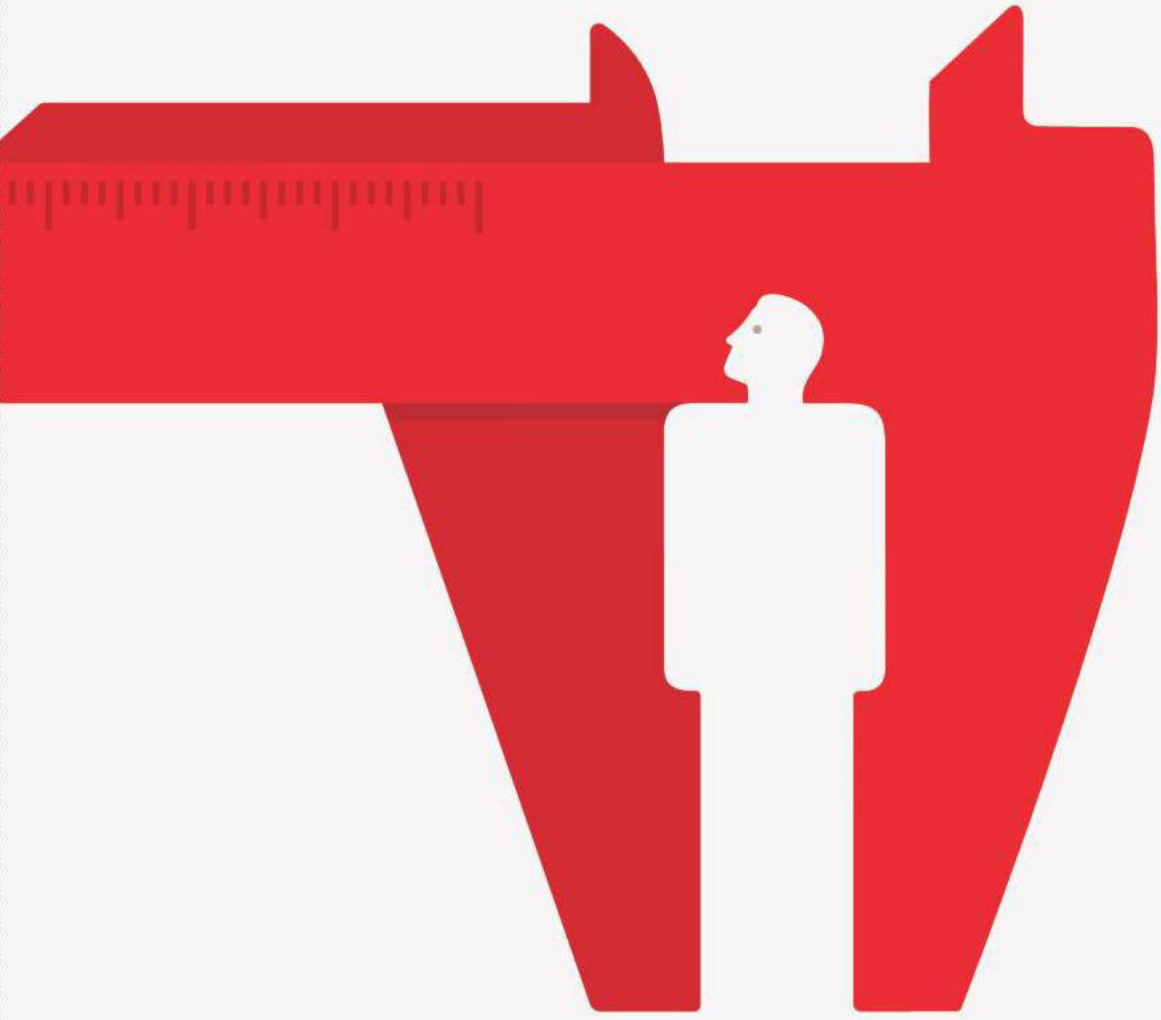
- 01 (09, 35) AES, Petersburg, Ind.
- 02 (47, 98) Alcoa, Newburgh, Ind.
- 03 (44, 06) American Electric Power, Rockport, Ind.
- 04 (32, 04) Duke Energy, Owensville, Ind.
- 05 (73, 59) Northern Indiana Public Service, Wheatfield, Ind.
- 06 (43, 23) PPL, Ghent, Ky.
- 07 (81, 89) PPL, Bedford, Ky.
- 08 (14, 67) PPL, Louisville, Ky.
- 09 (33, 15) Tennessee Valley Authority, Drakesboro, Ky.
- 10 (83, 44) AES, Manchester, Ohio
- 11 (45, 97) Duke Energy (since sold), North Bend, Ohio
- 12 (50, 34) FirstEnergy, Stratton, Ohio
- 13 (04, 38) General Electric, Homer City, Pa.
- 14 (88, 41) NRG Energy, Shelocta, Pa.
- 15 (86, 49) NRG Energy, New Florence, Pa.
- 16 (01, 76) Basin Electric Power Cooperative, Beulah, N.D.
- 17 (25, 21) Duke Energy, Crystal River, Fla.
- 18 (27, 51) Exxon Mobil, Baytown, Tex.
- 19 (05, 27) FirstEnergy, Haywood, W.V.
- 20 (66, 39) NRG Energy, New Roads, La.
- 21 (18, 96) Southern, Wilsonville, Ala.
- 22 (24, 14) Tennessee Valley Authority, Cumberland City, Tenn.

*There are no sites in Alaska or Hawaii

SOURCE: "AMERICA'S SUPER POLLUTERS," BY JAMIE SMITH HOPKINS. PUBLISHED ONLINE BY CENTER FOR PUBLIC INTEGRITY, SEPTEMBER 29, 2016 *www.publicintegrity.org/2016/09/29/20248/america-s-super-polluters*

Graphic by Tiffany Farrant-Gonzalez

AMAZING THINGS ARE HAPPENING HERE



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