Dear Ms. Laura Helmuth

Editor-in-Chief

Scientific American

With reference to Scientific American (October 2021 Issue):

This rings a natural-chord in my memory about my association with Banaras Hindu University (BHU-IIT) since my birth (09.03.1937) on its sprawling-Campus till May 1963, where Birla Temple [Lord Shiva and His associates including females, notably His wife Parvati; where birds used to chirp early in the morning heralding 'sun-rise'; which recently awarded me as the inaugural recipient of "ALUMNUS OF EMINENCE" on 13.02.2021 in Virtual (Video-Conferencing mode) {among two awardees:- 1. Prof. Prem Saran Satsangi, 2. Dr. Rajneesh Dube, Additional Chief Secretary, Government of Uttar Pradesh (India) with my befitting speech in response, vide Dayalbagh Herald March 16, 2021: ***edeiwww.education*** ***https://www.dei.ac.in/dei/edei/files/IIT%20BHU%20GH%20with%20sound%20clip.mp4***}]

With warm regards

P. S. Satsangi

Prem Saran Satsangi

(Sunday, 19.09.2021, 04:28 PM)

OCTOBER 2021 SCIENTIFICAMERICAN.COM

SCIENTIFIC AMERICAN

Unprecedented Arctic Wildfires

Competitive Birding

A Map of All Mathematics

A NEW FORCE OF NATURE?

An intriguing experiment may reveal a hidden world of physics

OCTOBER 2021

VOLUME 325, NUMBER 4

SCIENTIFIC AMERICAN

ON THE COVER
An experiment called Muon g-2 at Fermi National Accelerator Laboratory in Illinois measured excessive wobbling by particles called muons. The findings suggest new particles or forces beyond those in the Standard Model of particle physics may be involved.
Illustration by Maria Corte.

Cindy Arnold Fermi National Accelerator Laboratory

SCIENTIFIC AMERICAN

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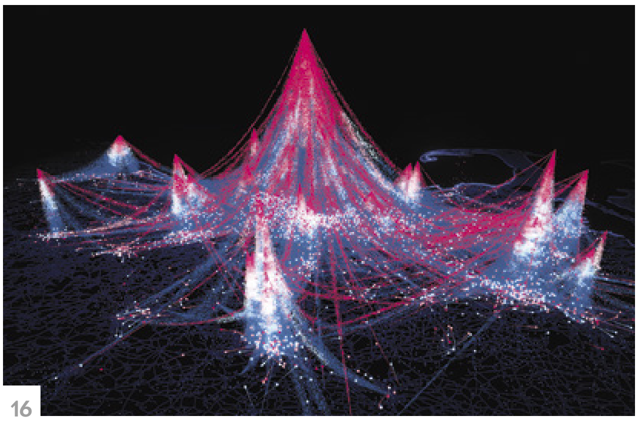

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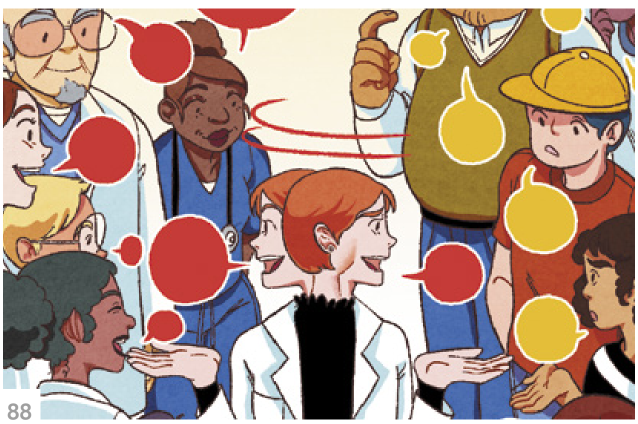

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Laura Helmuth is editor in chief of *Scientific American.* Follow her on Twitter @laurahelmuth

Big on Birds

Birds have been a great source of joy for many of us at *Scientific American* and, I hope, for many of you. We've been working at home during the pandemic and paying more attention to the wildlife in our neighborhoods, and we now take walks during the mornings and evenings rather than commuting during the best birding hours of the day. Seth Fletcher, who runs our features department, was entertained recently by a Carolina Wren shrieking like its dinosaur ancestors. Art director Mike Mrak sees Wild Turkeys strut through his yard. Christine Kaelin, who handles customer service, noticed the ridiculous variety of songs Northern Cardinals belt out. I suction-cupped a feeder to my office window and often have a White-breasted Nuthatch fly in during video meetings, make its grouchy call and leave with a peanut.

Kate Wong, an editor who specializes in evolution, got bit by the birding bug last year and has been sharing gorgeous photos of Osprey, Baltimore Orioles, lots of warblers and even a vagrant Roseate Spoonbill she bagged in Connecticut. She met up with some extreme birders this spring for the wildest side of birding—a Big Day, in which teams race across a set territory to identify as many bird species as they can in 24 straight hours. Her story on page 64 weaves ornithological observations in with some passionate characters and lots of low-stakes but high-tension drama.

When the Higgs boson was discovered in 2012, physicists had finally found all the particles predicted by the Standard Model of physics. Boom, done. But a couple of experiments have shown that particles called muons seem to wobble in weird ways, hinting that they may be interacting with additional particles beyond the ones we know about. In our cover story this month (*page 56*), Marcela Carena, a particle physicist at Fermilab in Batavia, Ill., says this odd finding could mean there is a fifth force of nature.

Knowledge builds on knowledge in every field, though in different ways. Mathematician Emily Riehl explains on page 32 that in math, a lot of progress has been made recently thanks to category theory, which shows how different mathematical concepts can be treated as alike in fundamental ways. It allows current mathematicians to manipulate ideas that stumped Isaac Newton and Carl Friedrich Gauss back in their times.

Sometimes progress comes in surprising ways. On page 82, author Anil Ananthaswamy reports that artificial-intelligence systems have come up with quantum physics experiments that humans never conceived of.

It's been another devastating year for wildfires, and although we hear more about the ones that destroy property or kill people, the fires raging in the Arctic may be some of the most consequential for climate change. Zombie fires are smoldering through the winter, permafrost is melting, and the insulating layer of duff is drying and easily ignited by lightning strikes, which are also increasing because of the climate emergency. On page 42, fire researchers Randi Jandt and Alison York describe the profound changes they've seen in Alaska.

As the global population grows, more people are at risk of hunger. Reducing food waste will be necessary to feed the world, limit greenhouse gas emissions and protect wild spaces. In a graphics-focused story on page 74, Chad Frischmann and Mamta Mehra of the research group Project Drawdown share projections for possible food futures.

Social scientists have found high levels of resilience in many majority-Black communities in the U.S. On page 50, writer Nancy Averett shares the latest research on how networks of mutual aid have flourished, some of which began before the Civil War, and how social capital helps people resist systemic oppression. SA

Illustration by Nick Higgins


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"Too many people in the scientific arena assume that technological advances will be able to solve our problems."

TED TRAINER *VIA E-MAIL*

June 2021

SUSTAINABLE COMMUNITIES

Ashish Kothari's "A Tapestry of Alternatives" explores ways of living around the world that offer inspirations for sustainability. The article is hopeful and enlightening, but Kothari may wish to consider the value of self-defense. Inevitably, in the "tapestry of alternatives" that he describes, there will arise knots of powers with values at odds with these communities. They will, because they can, seek the goods of the commons. What's to stop them? Ultimately it will be countervailing power exercised as self-defense, which is not in conflict with the other core values, as any well-trained and disciplined martial artist knows. By the way, there are thousands of local schools and traditions of martial arts that rightly should be considered part of the sphere of "cultural diversity and knowledge democracy" highlighted in the article.

Bill Cipra *Overland Park, Kan.*

I wish to commend you for publishing Kothari's article on the global "development" predicament. Too many people in the scientific arena assume that technological advances will be able to solve our problems while allowing the pursuit of normal development to continue delivering affluent lifestyles and ever growing gross domestic product. But an increasing number of people can see that we are on the road to catastrophic global breakdown, primarily because there is far too much producing and consuming going on, and our economic and cultural systems are fiercely committed to increasing the levels without limit. We cannot get to a sustainable and just world unless and until the conventional development paradigm is scrapped, and we shift to some kind of simpler way (see https://thesimplerway.info).

Ted Trainer *via e-mail*

*KOTHARI REPLIES: Cipra makes an important point. Indeed, the transitions toward an eco-*swaraj*—a community that practices self-rule merged with ecological sustainability—will face many such challenges. In my understanding, the values of "autonomy" or "self-determination," which are part of the vision, include the means and tools that are necessary to sustain them. Self-defense would be part of this.*

*How precisely people and communities defend their autonomy could vary greatly. Some movements have armed themselves with the explicit intention to use armed tactics only for self-defense, never for offense. And many others use Gandhian tactics of nonviolent defense. Indeed, the vast diversity of "martial" arts are part of cultural diversity, except that their use, if it is to be in sync with the values of eco-*swaraj*, would never be for offensive actions that proactively take away the autonomy and freedom of others. This is, of course, a complex subject and not possible to deal with satisfactorily in a brief comment.*

MYSTERY OF MIND

Christof Koch ends "The Brain Electric" with this most fundamental question: "What is it about the brain … that turns the activity of 86 billion neurons into the feeling of life itself?" Variations of Koch's provocative question about consciousness have, of course, dogged philosophers for millennia. Among the most influential was 20th-century British philosopher Gilbert Ryle, who put to rest the wrongheadedness of Cartesian mind-body dualism by metaphorically debunking this notion as the "ghost in the machine." Philosophers have since handed the baton off to neuroscientists, physicists and other scientists to figure out how the brain gives rise to consciousness.

Keith Tidman *Bethesda, Md.*

SCIENCE AND POLITICS

In response to "Do Republicans Mistrust Science?," by Naomi Oreskes [Observatory], I feel compelled to point out that trust is a two-way street. By mandating behaviors such as wearing masks to fight COVID-19 or using taxes and incentives to influence consumer choices to fight climate change, those in government are essentially saying that they don't trust us citizens to inform ourselves and make sound choices. Republicans strongly value individual liberties. So to them, the issue is the way the science is used by the government to justify further intrusions on the lives of its citizens.

Admittedly, some mistakenly feel the best way to fight back against such intrusions is to deceptively cast doubt on the science itself (as Oreskes points out has been done with both climate change and COVID-19). Although I strongly disagree with this tactic, I am sympathetic with its motivation. I and many others have a strong conviction that a free and open society is best served by a government that informs and empowers its citizens rather than one that treats us like we can't help ourselves.

Gerald Sontheimer *St. Louis, Mo.*

NOT-FOR-PROFIT DRUGS

"Deadly Kingdom," by Maryn McKenna, is a real wake-up call. Not only are viruses and bacteria a deadly threat, but now fungal diseases (which are far more difficult to treat) are an even greater one. The bigger problem, however, is that big pharma has refused to adequately develop new antiviral, antibacterial and antifungal medications

because they are not profitable enough.

The COVID-19 vaccines are *not* a valid example of the pharmaceutical industry rapidly developing vaccines on its own. Most of the mRNA vaccine research had already been done, and the U.S. government guaranteed that the industry would not lose any money if its vaccines failed. Further, the so-called free vaccines were fully paid for by taxpayers, as are the half a billion doses the U.S. has pledged to "donate" to the world. This is one more example of how capitalism, with its profit motive requirement, cannot meet the needs of the vast majority of the world's population.

John Jaros *Philadelphia*

EIGHT-ARMED BANDIT

"A Model Octopus," by Rachel Nuwer [Advances; March 2021], quotes multiple experts discussing the potential of big-brained cephalopods for widening the scope of research on animal intelligence.

Visiting an aquarium in England, I was shown a specimen with a 40-inch arm span that local fishers had brought in. I was told of a series of overnight thefts of fish that had been disturbing the staff. Because the perimeter security of the aquarium was uncompromised, it looked to be an insider job, casting shadows on everybody. All-night surveillance cameras were installed to try and work out what was going on.

The cameras revealed the octopus sliding outside of its tank and creeping across the floor to another tank of its choice. After helping itself to a neighbor as a late-night meal, it made the return journey to its own tank and climbed back inside, carefully pulling the lid back into its original position before settling down to digest its illicit meal.

Alan Waller *via e-mail*

ERRATA

"Deadly Kingdom," by Maryn McKenna, should have said that unlike animals, fungi have cell walls in addition to cellular membranes, not in place of them.

In "Fabric from Fungi," by Cypress Hansen [Advances], the photograph of an agarikon fungus was upside down. Additionally, Deborah Tear Haynes's position at Dartmouth College's Hood Museum of Art should have been described as "collections documentation manager," not "collections manager."

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A FORCE FOR EQUITY IN CANCER CARE

All too often, race, gender, geography or social status determines the quality of an individual's cancer care. Finalists for the 2021 Catalyst for Equity Award, part of the annual Cancer Community Awards, are standing up against such disparities.

According to the *American Cancer Society's Cancer Facts & Figures for African Americans 2019–2021*, the causes of inequalities in cancer care "are complex and reflect social and economic disparities and cultural differences that affect cancer risk, as well as differences in access to high-quality health care, more than biological differences."

The Cancer Community Awards (or C2 Awards)—presented by AstraZeneca's YOUR Cancer Program and Scientific American Custom Media—celebrate grassroots organizations and individuals making impactful changes for people with cancer. There are five distinct award categories. The Catalyst for Equity Award, a new category introduced this year, honors individuals and organizations that strive to overcome long-standing disparities in accessing preventive services and quality care, many of which have been made worse during the pandemic.

The 2021 finalists for the Catalyst for Equity Award bring breast-cancer education, screening and psychological support to a range of underserved groups and demonstrate how an individual or organization can develop models that could inspire positive changes for other communities. We had an opportunity to speak with each of these finalists about their work, and here's what they said.

BEULAH BRENT
EXECUTIVE DIRECTOR
SISTERS WORKING IT OUT

With more than 30 years spent providing breast cancer-screening services to underserved patients, Beulah Brent works to make health equity attainable for African American and Latina women in and around Chicago, Illinois. Under her leadership, Sisters Working It Out (SWIO) offers an integrated system of education, care coordination and psychosocial support for underserved communities in the area.

In the late 1990s, I landed a position as the manager of the mammography department at John Stroger Hospital. Within my first two years, I realized that we had some issues getting women to schedule a mammogram. So, we started our community health worker program to educate the women on the importance of getting a mammogram.

Sisters Working It Out came up with education solutions and strategies to make sure that we could go into the most underserved, underinsured communities in and around Chicago. We also help cancer patients and caregivers navigate their way through the system. But there are so many more people out there who need this assistance. Each year, we educate 12 women to come in to be navigators or community health workers. I'm so grateful to find women who are willing to give up their time to assist us. It is amazing!

CARMEN ORTIZ, PhD
FOUNDER AND
EXECUTIVE DIRECTOR
CÍRCULO DE VIDA CANCER SUPPORT AND RESOURCE CENTER

Carmen Ortiz founded the Círculo de Vida Cancer Support and Resource Center to help Spanish-speaking cancer patients and their families—many from lower-income, immigrant communities—navigate cancer and the complexities of the medical system. Her group has helped more than 5,000 patients and their families.

I was diagnosed with breast cancer in 1988, when I was 39, three months after finishing my doctorate in psychology. In 1989, after chemotherapy, I went to work at a mental health clinic with the hope of putting breast cancer behind me. I didn't want to talk about it nor be around anyone who had it.

Three to four years later, the mental health clinic received a call from a woman who'd been diagnosed with breast cancer, was depressed and wanted to speak with someone. My boss thought she would be a good client for me to work with. In working with this one client, I learned how little information and resources there were in Spanish. Working with her motivated me to use my experience to help other Latinas.

I became involved with a cancer center in San Francisco around 1994. I ran their Spanish language support group until 1998. I left, but continued running the group, and put together an advisory committee to begin discussing opening a cancer center. We received our nonprofit status in 2003, and Círculo de Vida was born.

EQUAL HOPE
REPRESENTED BY
ANNE MARIE MURPHY, PhD
EXECUTIVE DIRECTOR

Formerly known as the Metropolitan Chicago Breast Cancer Task Force, Equal Hope combats racial disparities in women's health. As of 2013, after work led by Equal Hope, Chicago was number one in the United States for reducing breast cancer deaths among Black women. Executive director and molecular geneticist Anne Marie Murphy describes how Equal Hope pursues equitable cancer care.

In 2007, we started publishing work showing that Chicago had large disparities in breast cancer mortality, where African-American women died at far higher rates than white women. In contrast to Chicago, cities such as New York had very low breast cancer disparities. We believe those gaps are likely driven by structural issues—such as access to health care and structural racism—rather than biological variation.

Based on our research, we have designed an array of interventions that include specific navigation programs helping women diagnosed with cancer get to a comprehensive facility and cancer quality improvement programs educating mammography technologists on how to position and compress breast tissue to get the best image. After a decade of work, the high death gap in Chicago has been drastically reduced. We have created a successful evidence-based model for understanding and reducing disparities in the diagnosis and treatment of breast cancer and are expanding to other women's cancers.

I think a catalyst for equity is a group that is willing to shake the cage for good, to create a better, more just world where everybody has an equal chance for long life and good health.

Finalists for the third annual C2 Awards were selected by a distinguished panel of judges who are a part of the broader cancer community. They include leaders from health-care systems, research institutes, advocacy groups and other organizations working to transform cancer care from one person's disease into a true community effort. The winners of all five 2021 C2 Awards will be announced at a virtual ceremony in October.

To learn more about the C2 Awards and the YOUR Cancer program, please visit YourCancer.org.

Protect Biodiversity's Protectors

Indigenous peoples have been conserving the land for millennia. The developed world should not evict them

By the Editors

In the late 19th century Yellowstone, Sequoia and Yosemite became the first of the great U.S. National Parks, described by author and historian Wallace Stegner as America's "best idea." But the parks were devastating for the Native Americans who had lived or hunted within their borders and who were expelled—essentially an act of colonialism in the name of conservation. In the 20th century similar reserves began to be carved out in developing countries, creating millions of "conservation refugees" even as neighboring forests were given over to extractive industries. The protected areas failed to offset the destructive aspects of development. Plant and animal species are disappearing faster than at any time since the event that wiped out most of the dinosaurs 65 million years ago. Even humans aren't guaranteed to survive.

The U.S. has taken one small step to make amends. In June, Secretary of the Interior Debra Haaland, the first Native American ever to hold a cabinet position, signaled her intent to safeguard both nature and justice by returning the National Bison Range to the Salish and Kootenai confederation. Now the Biden administration needs to go further. At the 2021 meeting of the United Nations Convention on Biological Diversity (CBD), it should ensure that an ambitious plan to promote biodiversity empowers Indigenous and other communities worldwide instead of punishing them for their success in conservation.

In 2016 biologist Edward O. Wilson responded to the biodiversity crisis by calling for half of Earth to be left to wilderness. His rallying cry has birthed the "30x30" campaign to protect 30 percent of Earth's land and sea surface by 2030. Backed by many scientists, major conservation organizations, the more than 60 member countries of the High Ambition Coalition for Nature and People, and $1 billion from a Swiss entrepreneur, the target is likely to be adopted by the CBD when it meets in October.

But critics charge that some advocates of 30x30 seek "a new model of colonialism" that forces those least responsible for climate change, biodiversity loss and other environmental crises to pay the highest price for averting them. 30x30 could be used by elites in democratically challenged nation-states as a pretext for seizing land from marginalized groups. The home ranges of Indigenous peoples currently shelter 80 percent of Earth's remaining biodiversity and sequester almost 300 trillion tons of carbon. Precisely because of this abundance, these areas are likely to be some of the first places targeted for "protection." If that happens, the very people who defend nature from the voracious appetites of the Global North, often at the cost of their lives, would be penalized for their efforts. Up to 300 million forest dwellers and others could be forced out of their territories, by one estimate.

Such seizures are already happening. In the Congo Basin, for example, armed eco-guards have brutally evicted Indigenous Pygmies from the rain forest to carve out protected areas. These wildlife reserves expanded following a CBD resolution in 2010 to dedicate 17 percent of Earth's terrestrial surface to nature. Yet the protected areas are surrounded by or sometimes even overlaid with oil, mining or logging concessions. Unsurprisingly, chimpanzee, gorilla and elephant populations have continued to decline even as Pygmy peoples have been consigned to poverty and misery.

There is a way to do global conservation right. Indigenous communities are as good as or better than governments at protecting biodiversity and already conserve a quarter of Earth's terrestrial surface. The CBD needs to ensure that they get secure rights to their territories, as well as the resources to defend them. Further, the signatories to the CBD should commit to returning some protected areas, which now cover around 17 percent of the planet's lands, to the control of the communities from which they were wrested.

The U.S. could lead the way in this effort. The Biden administration's vision for 30x30, released in May 2021, includes a pledge to support local populations, in particular Tribal administrations, in conserving and restoring biodiversity. The U.S. needs to take that resolve to the global stage at the U.N. meeting and help rescue nature and its most ardent defenders from the militarized conservation model it pioneered one and a half centuries ago. That is a crucial step toward a reprieve for the incredible life-forms that share our planet, as well as their Indigenous guardians. SA

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Illustration by Alix Pentecost Farren

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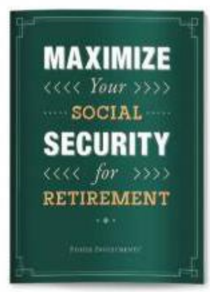

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The Supreme Court will weigh in on Mississippi's severely restrictive law

By Elizabeth Nash

When Texas Governor Greg Abbott signed a new abortion restriction into law on May 19, 2021, it marked a chilling milestone—a staggering 1,300 restrictions enacted by states since the U.S. Supreme Court protected abortion rights in 1973 in its *Roe v. Wade* decision. Unless rejected in court, it could block most abortion care in the state. Among many other harms, this would force Texans to travel an average 20 times farther to reach the nearest abortion provider. I have read and logged all of these 1,300 restraints—many as they were being enacted—in my 22 years at the Guttmacher Institute tracking state legislation on abortion and other issues related to sexual and reproductive health and rights. It's an astounding number, and although many of these laws were blocked in court, most of them are in effect today.

But the news from Texas wasn't the only bad news for abortion rights that week. Just two days earlier, on May 17, the Supreme Court announced that it would hear oral arguments on a Mississippi law—currently blocked from going into effect—that would ban abortion after 15 weeks of pregnancy. The news alarmed legal experts and supporters of abortion rights alike, with good reason.

A central tenet of *Roe* and subsequent Supreme Court decisions has been that states cannot ban abortion before viability, generally pegged at about 24 to 26 weeks of pregnancy. By taking a case that so clearly violates almost 50 years of precedent, the court signaled its willingness to upend long-established constitutional protections for access to abortion. As the legal experts at the Center for Reproductive Rights put it, "The court cannot uphold this law in Mississippi without overturning *Roe*'s core holding." And in fact, Mississippi followed up in July with a brief asking the justices to explicitly overturn that historic decision.

The Supreme Court that former president Donald Trump shaped, possibly for decades to come, by appointing conservatives handpicked by abortion rights opponents, is thus poised to deliver a potentially severe blow. Conservative state policy makers clearly feel emboldened by the 6–3 majority of justices opposed to abortion rights and a federal judiciary transformed by Trump's more than 200 appointments.

The decision to hear the Mississippi case comes as abortion rights and access are already under threat nationwide, with states on pace to enact a record number of abortion restrictions this year. As of August 5, 97 laws had been enacted across 19 states. That count includes 12 measures that would ban abortion at different points during pregnancy, often as early as six weeks—before most people even know they are pregnant. That is the highest number of restrictions and bans ever at this point in the year. For many people, affordable and accessible abortion care has already become an empty right on paper, even before the Supreme Court takes any new action. Currently 58 percent of women of reproductive age live in states that are hostile to abortion rights, facing multiple restrictions—from bans on insurance coverage to days-long waiting periods to intentionally onerous regulations that close down clinics—that build on one another to make abortion unobtainable for many.

A significant body of scientific literature shows that the adverse consequences of withholding abortion care are serious and long-lasting. Forcing someone who wants an abortion to continue a pregnancy requires them, against their wishes, to accept the great risks of pregnancy- and labor-related complications, which include preeclampsia, infections and death. And these risks fall much heavier on some communities than others. The U.S. has the highest maternal mortality rate among developed countries, with dramatic but preventable racial inequities caused by systemic racism and provider bias. Black and Indigenous women's maternal mortality rates are two to three times higher than the rate for white women and four to five times higher among older age groups.

The risks of serious consequences do not end with a safe delivery. The Turnaway Study by researchers at the University of California, San Francisco, found that denying wanted abortion care can have adverse effects on women's health, safety and economic well-being. For example, among women who had been violently attacked by an intimate partner, being forced to carry an unwanted pregnancy to term tended to delay separation from that partner, leading to ongoing violence. In addition, compared with women who got the abortion they sought, those who did not obtain a wanted abortion had four times greater odds of subsequently living in poverty. They also had three times greater odds of being unemployed and were less likely to be able to have the financial resources for basic needs such as food and housing.

The impact of restrictive policies is even further magnified in regions of the country where hostile states are clustered together, such as the South, the Great Plains and the Midwest. For people in those regions, traveling to a state with better access may not be an option because of the long distances and logistical or financial hurdles involved.

These barriers to abortion care are the biggest obstacle for people who are already struggling to get by or who are marginalized from timely, affordable, high-quality health care—such as those with low incomes, people of color, young people, LGBTQ individuals and people in many rural communities. Any further rollback of abortion rights would once again affect these populations disproportionately.

If the Supreme Court uses the Mississippi case to further undermine women's rights to health care, things will get ugly—and fast. Twelve states have so-called trigger bans on the books (or nearly so)—meaning they would automatically ban abortion should *Roe* fall. Also, 15 states (including 10 of the states with trigger bans) have enacted early gestational age bans in the past decade. None of these early abortion bans are in effect, but with *Roe* overturned, many or all of them could quickly be enforced.

Elizabeth Nash is the principal policy associate for state issues at the Guttmacher Institute's Washington, D.C., office.

Even if abortion rights are weakened by the Supreme Court rather than overturned, these same states will look to adopt restrictions that build on the decision.

But there are lots of ways to fight back. States supportive of abortion, primarily in the West and the Northeast, must step up to protect and expand abortion rights and access—both for the sake of their own residents and for others who might need to travel across state lines to seek services. Congress and the Biden administration must do their part by supporting legislation such as the Women's Health Protection Act that would essentially repeal many state-level restrictions and gestational bans. Another bill that needs support is the EACH Act; it would repeal the harmful Hyde Amendment, which bars the use of federal funds to pay for abortion except in a few rare circumstances, and allow abortion coverage under Medicaid. There are also tireless advocates and volunteers, including managers of abortion funds in many states, who already assist abortion patients in paying for and accessing care. No doubt these vital efforts will increase dramatically if more states move to ban all or most abortions.

As federal protections for abortion are being challenged, people may go other routes to get an abortion. Abortion-inducing medication, whether under the management of a clinician in person or via telehealth or self-managed, is a safe and effective method, and many have been able to get such pills through the mail during the COVID pandemic. But here, too, barriers loom large. More state legislatures are looking to join the 19 that already ban abortion via telehealth. And just this year states started to enact bans on sending abortion-inducing pills through the mail.

Abortion is health care, plain and simple. There were more than 860,000 abortions in the U.S. in 2017, and at current rates almost one in four women will have an abortion by age 45. Supporters of abortion rights have to hope for the best and prepare for the worst. Most of all, we must stay in this fight until every person who needs an abortion is able to get safe, affordable and timely care. SA

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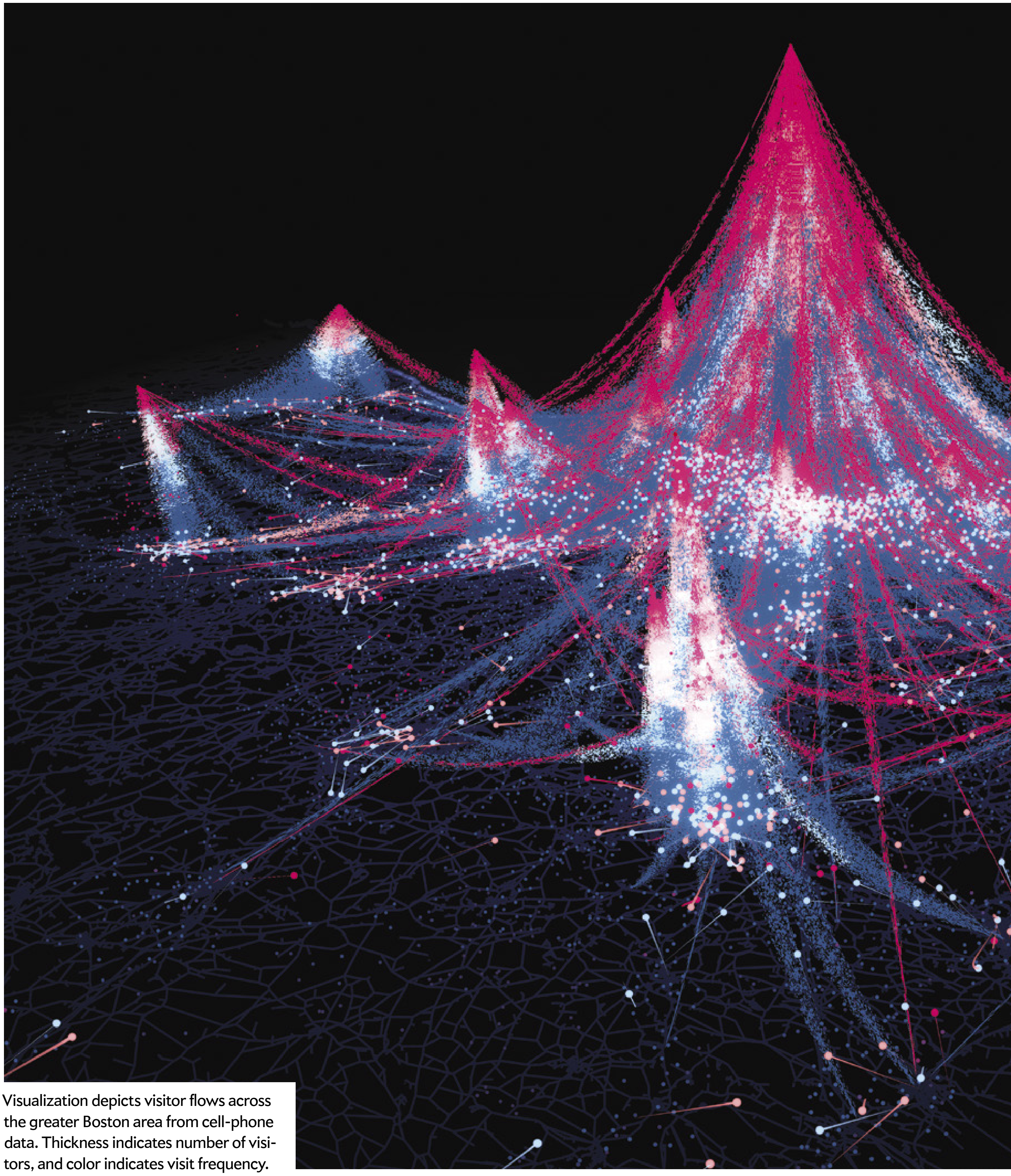
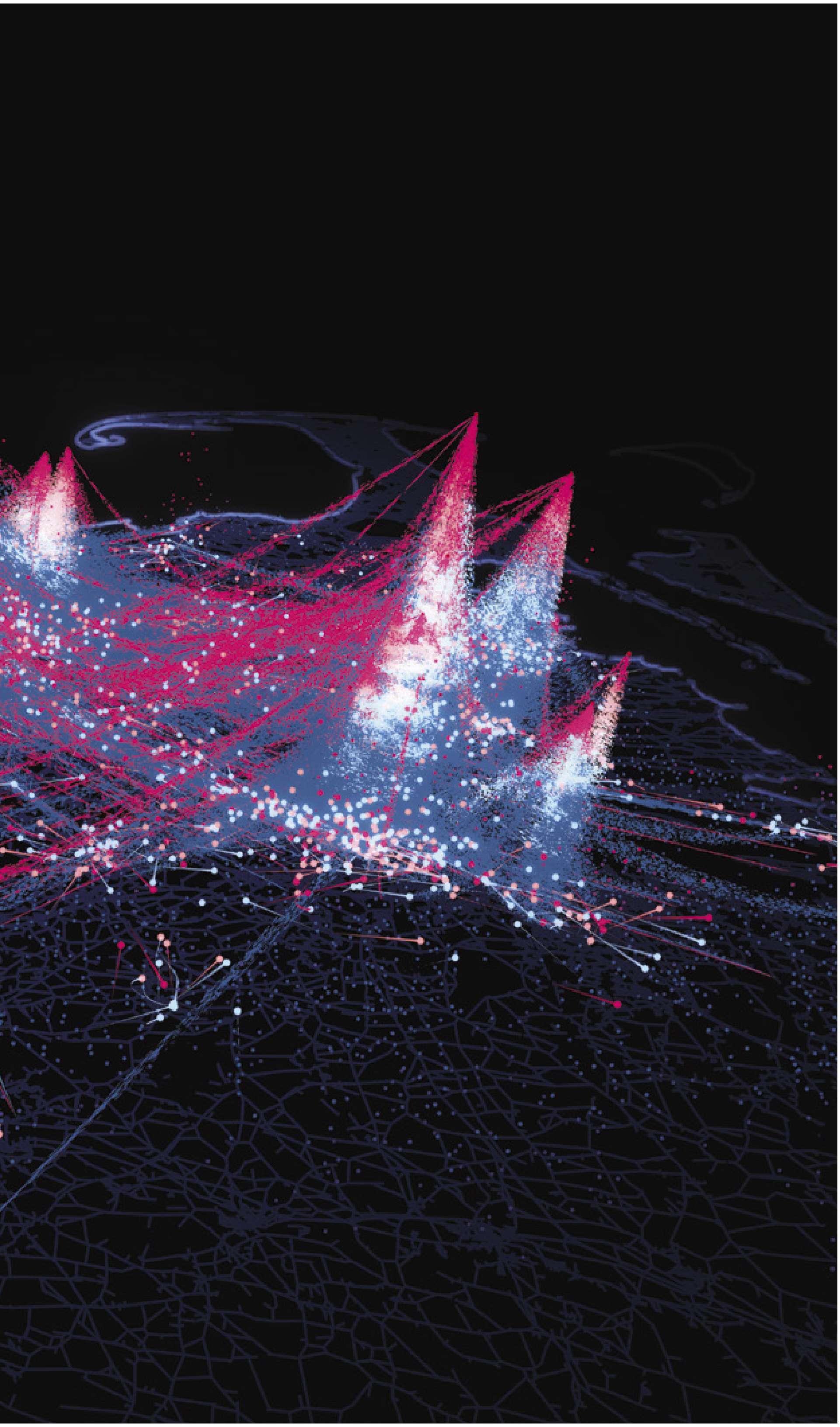
Illustration by Cat O'Neil

ADVANCES



Visualization depicts visitor flows across the greater Boston area from cell-phone data. Thickness indicates number of visitors, and color indicates visit frequency.

INSIDE



MIT Senseable City Laboratory

MATHEMATICS

Math Transit

A simple formula predicts people's movements in cities around the world

The people who happen to be in a city center at any given moment may seem like a random collection of individuals. But new research featuring a simple mathematical law shows that urban travel patterns worldwide are, in fact, remarkably predictable regardless of location—an insight that could enhance models of disease spread and help to optimize city planning.

Studying anonymized cell-phone data, researchers discovered what is known as an inverse square relation between the number of people in a given urban location and the distance they traveled to get there, as well as how frequently they made the trip. It may seem intuitive that people visit nearby locations frequently and distant ones less so, but the newly discovered relation puts the concept into specific numerical terms. It accurately predicts, for instance, that the number of people coming from two kilometers away five times per week will be the same as the number coming from five kilometers twice a week. The researchers' new visitation law, and a versatile model of individuals' movements within cities based on it, was reported in *Nature*.

"This is a super striking, robust result," says Laura Alessandretti, a computational social scientist at the Technical University of Denmark, who was not involved in the study but co-wrote an accompanying commentary. "We tend to think that there are lots of contextual aspects that affect the way we move, such as the transportation system, the morphology of a given place, and socioeconomic aspects. This is true to some extent, but what this shows is that there are some robust laws that apply everywhere."

The researchers analyzed data from about eight million people between 2006 and 2013 in six urban locations: Boston, Singapore, Lisbon and Porto in Portugal, Dakar in Senegal, and Abidjan in Ivory Coast. Previous analyses have used cell-phone data to study individuals' travel paths; this study focused instead on locations and examined how many people were visiting, from how far and how frequently. The researchers found that all the unique choices people make—from dropping kids at school to shopping or commuting—obey this inverse square law when considered in aggregate. "The result is very simple but quite startling," says Geoffrey West, an urban scaling theorist at the Santa Fe Institute and one of the paper's senior authors.

One explanation for this strong statistical pattern is that traveling requires time and energy, and people have limited resources for it. "There is something really very fundamental at play here. Whether you live in Senegal or in Boston, you try to optimize your day," says study lead author Markus Schläpfer of ETH Zurich's Future Cities Laboratory in Singapore. "At the core is the effort that people are willing to invest collectively to travel to certain locations."

Understanding these patterns is important not only for planning the placement of new shopping centers or public transportation but also for modeling disease transmission within cities, says Kathleen Stewart, a geographer and mobility researcher at the University of Maryland who was not involved in the study.

Many researchers estimate travel with "gravity models," which assume that movement between cities is proportional to their population sizes. But these models do not account for travel patterns within cities—information that is particularly critical in tackling disease transmission. Northeastern University epidemiologist Sam Scarpino, who was not involved in the study, says models based on this new finding might better track that flow. For example, New York City residents are more likely to make short, frequent trips within their own borough (such as Manhattan or the Bronx) and fewer trips to a distant borough.

"Those organizational patterns have really profound implications on how COVID will spread," Scarpino says. In a smaller rural location, where many people regularly go to the same church or grocery store, the entire town will experience sharp peaks of infections as the virus sweeps through the community. But in a bigger city, the propagation takes longer, he explains, because mini epidemics can occur in each neighborhood somewhat separately.

Stewart adds: "The authors demonstrate that their visitation law—that takes into account both travel distance and frequency of visits in a way that other models do not—outperforms gravity models when it comes to predicting flows between locations." *—Viviane Callier*

PALEOARCHAEOLOGY

Domesticated Diets

Ancient poop contains clues to dogs' evolving digestion

The shift from hunting and gathering to farming altered human evolution—and that of our closest companions, dogs. Coprolites, or fossilized poop, are a "phenomenal" source of information on how diet influenced such changes, says University of Oxford archaeologist Greger Larson. "They're snapshots of somebody's gut." A recent analysis of 13 Bronze Age canine coprolites reveals how shifts to a grain-based diet affected dogs' gut microbes, which may have played a role in the animals' domestication.

Researchers sequenced DNA from the 3,600- to 3,450-year-old fossils, which were found at the site of an ancient agricultural community in northeastern Italy. Dog DNA in the coprolites had fewer copies of a gene that encodes amylase, a digestive protein that breaks down starches in the gut, than that of most modern dogs. Many of today's wolves lack this gene altogether, and scientists typically attribute the divergence to domesticated dogs' shift from meat-heavy to grain-rich meals.

But along with an animal's own proteins, gut microbes also aid digestion. When the researchers sequenced microbial remnants in the fossilized feces, they found evidence of bacteria that produce high amounts of amylase. The dogs' own genomes had not yet fully evolved to handle the grainy diet of their farming domesticators, "so they were complemented by microbes," says University of Bologna microbiologist Marco Candela, senior author on the study, which was published in *iScience*.

Although these fossilized microbiomes shed light on an intermediate stage between wolves and dogs, domestication was not a simple linear process, says Durham University zooarchaeologist Angela Perri, who was not involved with the study. "It feels neat and clean to say it's a progression from X to Y to Z," she says, but consistent interbreeding between wild and domesticated canines complicates things. And even modern dogs carry varying numbers of amylase genes, notes Larson, who also was not on the research team. Still, Perri says it is significant that microbes may have picked up the slack where the dogs' own genomes fell short. This phenomenon might have also occurred in human guts during our shift from a hunter-gatherer diet to a farming one—a possibility Candela and his colleagues are now examining.

Perri notes that the new research demonstrates how much can be learned from fossilized animal excrement, a historically untapped and underappreciated resource from human settlements. "Usually in archaeology, human material is difficult to get a hold of," she says. "But no one is fighting over dog poop." *—Tess Joosse*

Illustrations by Thomas Fuchs

IN THE NEWS

Quick Hits

By Tess Joosse

U.S.

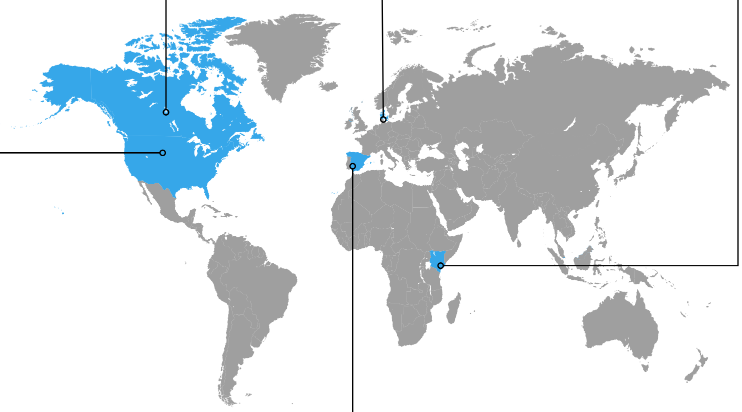
Scientists discovered strange DNA strands, which they dubbed "Borgs," buried in California mud. The strands are not technically alive and are made of genes scavenged from microbes. These chains—the longest extrachromosomal genetic material ever found—most likely enter single-celled archaea and help them break down methane.

CANADA

Spongelike fossils found in 890-million-year-old reefs near Canada's northwestern coast might record the earliest-known animal. The ancient specimens bore branching tubes that resemble the skeletons of modern organisms used to make commercial bath sponges.

DENMARK

Examination of the "bog body" Tollund Man's stomach reveals his last meal: mixed-grain porridge and fish. Along with his corpse, the meal was pristinely mummified after he was strangled and thrown into a peat bog around 350 B.C.



KENYA

Researchers suspect illegal fishing is behind a mass die-off of sea turtles on Kenya's central coast. The COVID pandemic has curbed monitoring in the area, leaving shallow waters that are home to young turtles vulnerable to trawlers.

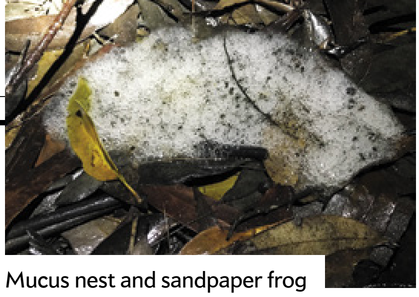
SPAIN

Though it has no ears, Neptune grass—an ecologically critical species in the Mediterranean—is sensitive to noise pollution. Researchers found that exposing the seagrass to artificial noise for two hours damaged elements of the plant required for energy storage and gravity detection.

TAHITI

Computers strapped to carnivorous rosy wolf snails (*Euglandina rosea*) revealed how another mollusk, *Partula hyalina*, evades the former's predation. Captured data revealed that *P. hyalina* can tolerate 10 times more sunlight and uses it to dodge the shade-acclimated *E. rosea*.

For more details, visit www.ScientificAmerican.com/oct2021/advances



Mucus nest and sandpaper frog

ANIMAL BEHAVIOR

Home Sweet Foam

Frogs whip up drought-defying slime nests for their eggs

Frothy mucus might not sound like the most inviting living space, but for some frogs' offspring it is a lifesaving refuge from drought. The amphibians often lay their gelatinous eggs in pools of water to provide the moisture needed to develop properly—but those pools can dry up. "The biggest cause of [frog] offspring mortality is desiccation," says University of Newcastle ecologist John Gould.

When studying frogs in Australia's Watagan Mountains, Gould was surprised to find evaporated puddles where eggs thrived for days, swaddled in nests their mothers whip up by aerating mucus secretions with their toes. "You could see embryos still alive and kicking," he says.

Scientists had previously hypothesized that several frog and toad species use foam to protect eggs from desiccation, but few studies had tested the idea. So Gould and his colleagues monitored 641 mucus nests built by the sandpaper frog, *Lechriodus fletcheri,* to determine whether embryos were surviving dry mountain conditions. They also conducted the first laboratory experiments to closely follow eggs' development in nests deprived of water.

The team found that the embryos could indeed successfully develop in a dried-up pool if the eggs encasing them were protected by slimy frog foam. In some nests stranded on dry land, embryos even endured well after full development, until a pool was replenished by rain—and a few successfully hatched into tadpoles. "The froth nest acts almost like a life-support system that sustains the viability of the eggs," Gould says. He also found that larger nests provided more protection, and eggs closer to the core could survive longer. The new work is detailed in *Ichthyology & Herpetology.*

Elisa Barreto Pereira, an ecologist at Brazil's Federal University of Goiás who was not involved in the study, says froth nests could be crucial to helping frogs survive as the climate changes. "The foam nest is an important adaptation," she says—one that evolved several times in different frog groups and continents when Earth's average temperature peaked about 55 million years ago. *—Sandrine Ceurstemont*

John Gould *(left)*; **NHP** and **Photoshot** *Science Source (right)*

MATERIALS SCIENCE

A Solid Charge

Concrete buildings could serve as rechargeable batteries

Concrete, after water, is the world's most used material. Because it already surrounds us in the built environment, researchers have been exploring the idea of using concrete to store electricity—essentially making buildings that act as giant batteries. The idea is gaining ground as many places come to increasingly rely on renewable energy from the wind and sun. Rechargeable batteries are necessary when winds die down or darkness falls, but they are often made of toxic substances that are far from environmentally friendly.

Experimental concrete batteries have managed to hold only a small fraction of what a traditional battery does. But one team describes in the journal *Buildings* a rechargeable prototype material that could offer a more than 10-fold increase in stored charge, compared with earlier attempts.

A concrete battery that houses humans might sound unlikely. Still, "you can make a battery out of a potato," notes Aimee Byrne, a structural engineer at Technological University Dublin, who was not involved in the new study. In a future where sustainability is key, she likes the idea of buildings that avoid waste by providing shelter *and* powering electronics.

"This is adding extra functions to the current building material, which is quite promising in my view," says study co-author Emma Zhang, who worked on the new battery design at Chalmers University of Technology in Sweden and is now a senior development scientist at technology company Delta of Sweden. She and her colleagues mimicked the design of simple but long-lasting Edison batteries, in which an electrolyte solution carries ions between positively charged nickel plates and negatively charged iron ones, creating an electrical potential that produces voltage. In this case, conductive carbon fibers mixed into cement (a main ingredient of concrete) substitute for the electrolyte. The researchers embedded layers of a carbon-fiber mesh, coated in nickel or iron, to act as the plates.

This setup proved capable of discharging power and then recharging. "The fact that they've managed to recharge it to some degree, I think that is a very important step to where we need to be," Byrne says. Like its inspiration, the prototype is long-lasting—Edison batteries can operate for decades—and it resists overcharging, Zhang adds: "You can abuse this battery as much as you want without jeopardizing the performance."

Although the new design stores more than 10 times as much power as earlier attempts, it still has a long way to go: 200 square meters of the concrete "can provide about 8 percent of the daily electricity consumption" of a typical U.S. home, Zhang says.

This contribution is not enough to compete with today's rechargeable devices. "We're getting milliamps out of [cement-based batteries]—we're not getting amps," Byrne says. "We're getting hours as opposed to days of charge." She adds, however, that "cement-based batteries are completely in their infancy compared with other battery designs."

The earliest batteries, including Thomas Edison's, were simple and bulky. Researchers experimented with new materials and designs for more than a century to develop today's small, efficient devices. Byrne suggests concrete-based energy storage could undergo a similar evolution. "The whole idea is that we're looking far into the future," she says. "We're playing the long game." *—Sophie Bushwick*

This South Australian forest reflects light indicative of life.

BIOCHEMISTRY

Life Sensor

A high-flying detector could keep tabs on life on Earth—and maybe beyond

Life on our planet is characterized by a preference for particular forms of various molecules over their mirror images. DNA molecules, for example, always have a “right-handed” curl, whereas all known life uses only “left-handed” amino acids to build proteins. Nonliving matter typically shows no such preferences. Researchers have seized on this distinction to design an instrument dubbed FlyPol, which uses light to track plant life from a fast-moving helicopter more than a kilometer overhead.

When light reflects off a concentration of molecules with the same handedness, called homochiral molecules, some of this light becomes circularly polarized: the reflected waveforms corkscrew in a clockwise or counterclockwise direction. FlyPol, a spectropolarimeter, measures how much light is transformed in this way as it bounces back from sunlit landscapes. The quantity of this polarized light, observed over a range of wavelengths, is like a fingerprint that reveals not only the type of organism (grass, tree or alga—FlyPol is calibrated for plants) but also details about its health. Inanimate sources have profiles with no discernible features.

“The signal in plants is strongly dependent on the larger-scale molecular structure,” says University of Bern astrobiologist Lucas Patty, lead author of a new paper describing FlyPol in *Astronomy & Astrophysics*. “If the plant is under drought stress, for example, the membranes can swell a bit”—and that comes through in slightly flattened intensity peaks of reflected light. Patty says the technique could help assess the health of ecosystems affected by climate change, deforestation or the spread of invasive species.

Until recently, stable measurements were possible only in controlled laboratory settings because they involve such a tiny portion of the detectable light. But FlyPol upgraded the lab setup to work in the field. “Overall, it’s just a really cool result,” says Massachusetts Institute of Technology astrochemist Brett McGuire, who was not involved in the study. “They pretty convincingly show that they can discriminate between areas that have an awful lot of life versus areas that don’t.”

Perhaps most enticing is the method’s potential to someday scan for life on other planets. Scientists currently know of no other mechanisms, besides molecules generated by life, that can cause complex circularly polarized light signals. Although life elsewhere might exist without homochiral molecules, their presence would be a solid hint of something living. “It’s one of the few ways of detecting life that is essentially free of false positives,” Patty says—although he notes that significant hurdles remain before this detection process would be feasible.

When scanned from near Earth, such a signal would be extremely faint in planets around distant stars, according to M.I.T. astrophysicist Sara Seager, who was also not part of the study. “It’s hard to say if we could pull this off in the next generation of telescopes,” she says. “It’s probably a couple of generations down the line.” Yet Seager says this methodology and experiment, with real-world flora measurements, are a great start to someday studying faraway worlds.

For now next steps include testing FlyPol over more landscapes and collaboration on an instrument to measure Earth’s signals from the International Space Station. “From the ISS the spatial resolution will still be quite high,” Patty says, so one would expect to get large signals when measuring above the Amazon, for instance, and flat signals from Antarctica.

—*Connie Chang*

Abstract Aerial Art *Getty Images*

North Atlantic right whales

TECH

Deep Listening

New tech pinpoints whale calls

Fewer than 400 North Atlantic right whales remain in the wild, and not even 100 of them are breeding females. Their biggest survival threats are boat strikes and entanglement in fishing gear. Protecting these whales, such as by diverting boats from dangerous encounters, requires locating them more reliably—and new technology, described in the *Journal of the Acoustical Society of America,* could help make that possible.

To listen for marine life, researchers often deploy underwater microphones called hydrophones on buoys and robotic gliders. The recorded audio is converted into spectrograms: visual representations of sound used to pinpoint, for instance, specific whale species' calls. But those distinctive sounds are often drowned out by other noise. In recent years researchers have used a machine-learning technique called deep learning to automate this analysis, but background sounds still hinder reliability.

Now researchers have trained two deep-learning models specifically to cut through the noise. They started by giving the models thousands of "clean" spectrograms with only North Atlantic right whale calls. Then they slowly added in thousands of spectrograms contaminated with typical background sounds, such as tanker engines. The resulting algorithms can successfully turn noisy spectrograms into clean ones, cutting down on false alarms and helping spot whales before they reach dangerous areas, the scientists say.

Shyam Madhusudhana, a Cornell University data engineer, who was not involved in the study, says he would want to see if such models could be used to locate other marine mammals, too. "Humpback whales and dolphins have much more complex speech pathways than the right whale," he notes. And University of East Anglia machine-learning researcher Ben Milner, one of the study's authors, wants to take this technology above water as well—to Ukrainian forests, where he hopes to identify animals near the site of the 1986 Chernobyl disaster.

University of St. Andrews behavioral ecologist Peter Tyack, who was not involved in the study, says this new system should be used to figure out where whales are throughout the year, so that these areas can be protected. "In terms of estimating the density and abundance of these whales in places where it's hard to see them," Tyack says, "this technology could be fantastic."

But he warns that it should not be the only approach to preventing ship strikes or entanglement. In his work, Tyack has found that North Atlantic right whales can be silent for hours at a time—so passive acoustic monitoring could easily miss one. And killing just a few, he adds, "could lead to extinction of the population." *—Sam Jones*

Francois Gohier and **VWPics** *Alamy Stock Photo*

MEDICINE

Detector Mask

Biological circuits for garments reveal COVID infection and more

Masks and testing have been key to the COVID-19 pandemic response—and now devices that combine the two may be on the way. Harvard University and Massachusetts Institute of Technology researchers used synthetic biology to create a face mask that accurately detects the COVID-causing virus.

Synthetic biologists use biological parts to build various devices, including sensors that detect genetic sequences. Previous efforts have used engineered bacteria in these sensors, but living cells bring challenges (like keeping them fed) and biohazard risks. The new research makes wearable devices with freeze-dried "cell-free" circuits built from genes, enzymes and other cell components, which can be placed on porous, flexible materials and easily stored. (The researchers described adding such circuits to paper in 2014.) "This work's important advance is converting bench-top technology to wearable devices," says bioengineer Xinyue Liu, who develops living sensors at M.I.T. and was not part of the new study. Such tools could allow for simplified on-site testing.

The study, published in *Nature Biotechnology,* describes adding cell-free sensors to elastics, textile threads and paper to detect the virus that causes COVID-19 (SARS-CoV-2), Ebola virus, MRSA, a chemical nerve agent and more. Some of these sensors, including those used in the new face mask that flags SARS-CoV-2, rely on CRISPR technology: When "guide" RNAs match target DNA, they activate an enzyme that cuts the nucleic acids (the DNA "letters"). This particular enzyme also cuts other nearby nucleic acids, freeing a fluorescent protein that emits light. The technique makes for versatile, "programmable" sensors that could be quickly adapted to detect virus variants.

The prototype mask activates with a push-button that rehydrates the sensor, starting reactions that break the virus apart and amplify its DNA for detection. The full process produces a color change within 90 minutes of activation—say, when worn by a hospital patient. "Breath is a nice source of noninvasive sampling that has the right concentrations," says University of Freiburg sensor expert Can Dincer, who was not involved in the new study. "The application really fits the needs of our current situation."

Sensitivity was similar to most lab tests'. "The 'gold standard' would still be your lab-based PCR tests, but we're in the ballpark," says bioengineer and senior author James Collins. The single-use masks need no power source nor operator expertise and work at typical room temperature and humidity.

Collins hopes to commercialize the mask to sell for around $5. Similar genetic-circuit wearables, he adds, could aid health-care workers, military personnel, first responders, and others in the field. *—Simon Makin*

CLIMATE

Burning Up the Past

Today's wildfires are taking us into uncharted territory

With smoke from blazing forests in the U.S. West tinting skies ochre this year and last, residents and researchers alike asked, "How much worse can fire seasons get?" University of Montana fire paleoecologist Philip Higuera has spent his career trying to determine the answer by looking at history. "If we're all wondering what happens when our forests warm up," he says, "let's see what happened in the past when they warmed up."

The central Rocky Mountains' subalpine forests grow in cool, wet conditions and burn less readily than their lowland counterparts. To find out how frequently these tough woodlands nonetheless have caught fire through the ages, Higuera and his colleagues combined records from modern satellite-observed fires, fire scars in tree rings from the 1600s onward, and flecks of charcoal that settled in lakes over thousands of years. The study found that from 2000 to 2020, the forests burned 22 percent faster than they did during an unusual warming period that started in A.D. 770 and saw the area's highest temperatures prior to the 21st century. Most of this burn rate increase, as well as 72 percent of the total area burned between 1984 and 2020, resulted from fires in 2020 alone.

Overall, these forests have not burned frequently—until the past two decades. The gap between extreme fire years in the U.S. is narrowing as the climate warms, and Higuera does not think this pattern will reverse any time soon. The new research is detailed in the *Proceedings of the National Academy of Sciences USA*. Higuera finds the recent unprecedented fire seasons unsurprising but still agonizing. "I've spent 20 years writing about this," he says. "But I have not spent 20 years thinking about how this would feel."

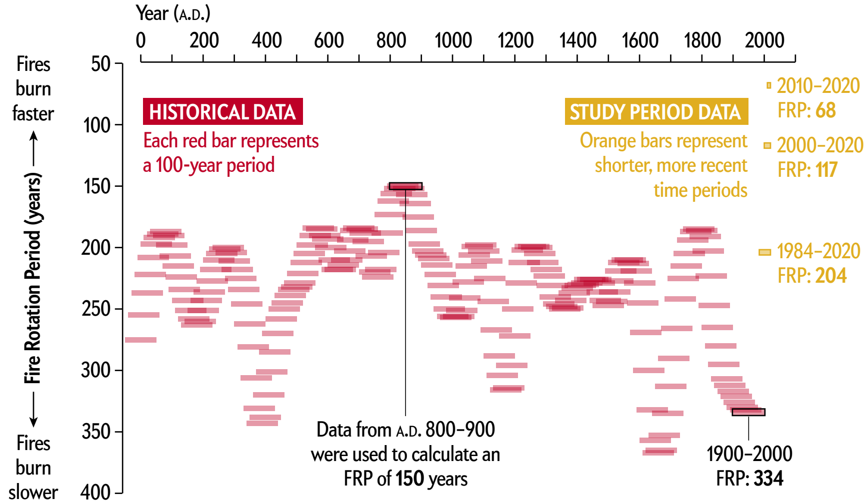
This work shows that the past may no longer guide us when it comes to understanding and handling wildfires, says Humboldt State University environmental geographer Rosemary Sherriff, who was not involved in the study. "We have to accept that we're going to see an increase in fire activity," she says. "We have to adapt to the new norm."

Many communities hit by recent wildfires have fire-protection plans, Higuera adds, but "they're based on our expectations that these forests burn once every few centuries. That's not where we are. That's not where we're going."

—Rebecca Dzombak

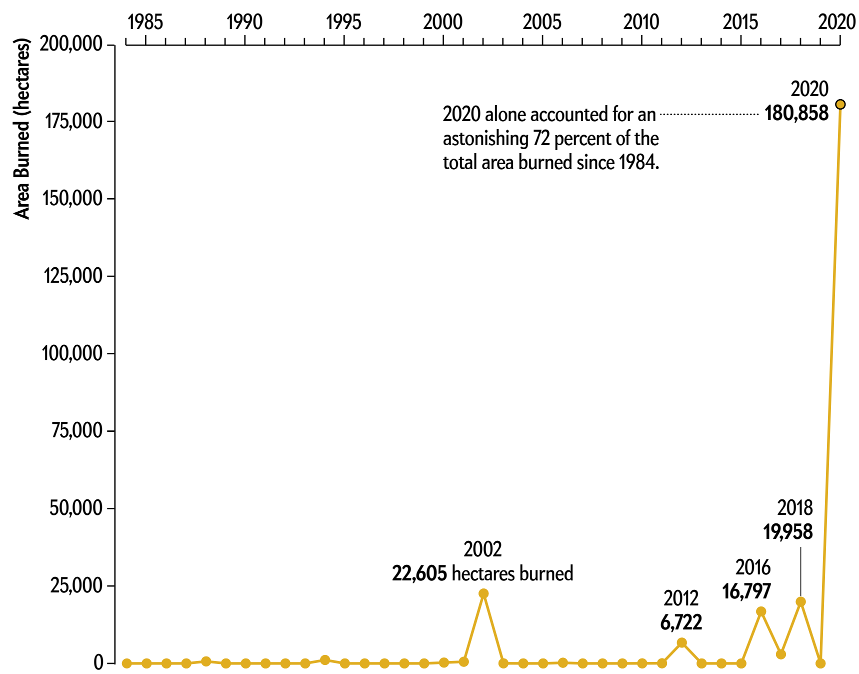
A 2,000-Year Record

A fire rotation period (FRP) is the amount of time it would take to burn an area equal in size to a study area if burning were to continue at a given rate. A smaller FRP value means that fires burn faster. An FRP is typically based on many years' worth of data because fluctuations from one year to the next can be quite large. In the graph below, red bars show FRPs calculated for 100-year time spans up to 2000. Orange bars represent shorter time spans within the study period 1984–2020.



Area Burned in the Subalpine Forests, 1984–2020

The graph shows the total area burned each year in the subalpine forests of the researchers' focal study area, a region of the central Rocky Mountains with a relative abundance of historical fire data.



Sources: "Rocky Mountain Subalpine Forests Now Burning More Than Any Time in Recent Millennia," by Philip E. Higuera, Bryan N. Shuman and Kyra D. Wolf, in *Proceedings of the National Academy of Sciences USA*, Vol. 118, No. 25; June 14, 2021; Dryad https://doi.org/10.5061/dryad.rfj6q579n (data and code for study)

Graphic by Amanda Montañez

BIOLOGY

Science in Images

By Harini Barath

True to their name, glasswing butterflies sport remarkably transparent wings that help them hide in plain sight. New work shows how narrow, bristlelike scales and a waxy, glare-cutting coating combine to make parts of the wings nearly invisible.

Most moths and butterflies get their vibrant colors from flat scales that tile the wing surface like shingles; relatively few species have clear wings. Nipam Patel, an evolutionary and developmental biologist at the Marine Biology Laboratory, first investigated the wings of several such species with his students in an embryology class. “It was amazing,” he says, “because they found every way you could imagine to have a transparent wing—from having see-through scales to no scales at all.”

Previous studies that explored the structural diversity and optical properties of wing transparency involved adult specimens held in museums, so the developmental processes underlying transparency were largely unknown. For a new study in the *Journal of Experimental Biology,* Patel and his colleagues raised glasswing butterflies and tracked their wing development, creating the first detailed time-series record of the process. Their work shows that glasswing butterflies grow sparse, narrow bristles for the clear patches as well as broader scales (*top right*), using fewer scale precursor cells than other butterflies do.

Colorless wings can be shiny, so butterflies have evolved ways of reducing reflected light. Using powerful electron microscopes, the researchers took a closer look at nanopillars—minuscule structures that are known to prevent glare—scattered on the glassy wings’ surface. The team saw that a regularly spaced layer of nanopillars made from chitin, a fibrous substance found in insect exoskeletons, supports an irregular layer of nanopillars made from a waxy chemical that significantly lowers the amount of reflected light. The researchers say these findings could inspire new antireflective materials.

The study also sets the groundwork for future efforts to pinpoint the genetic mechanisms by which butterfly and moth color (or the lack thereof) evolves, says Cornell University ecologist Robert Reed, who was not involved with the study. “Scales are the evolutionary innovation that marks moths and butterflies,” Reed notes, “so it’s kind of remarkable that there has been a reversion of sorts [from color to colorless] in some species.”

For more, visit www.ScientificAmerican.com/science-in-images

Aaron Pomerantz

PSYCHOLOGY

Healing Tales

Listening to a story reduced pain and stress in hospitalized kids

Parents, teachers and caregivers have long sworn by the magic of storytelling to calm and soothe kids. Researchers working in pediatric intensive care units have now quantified the physiological and emotional benefits of a well-told tale.

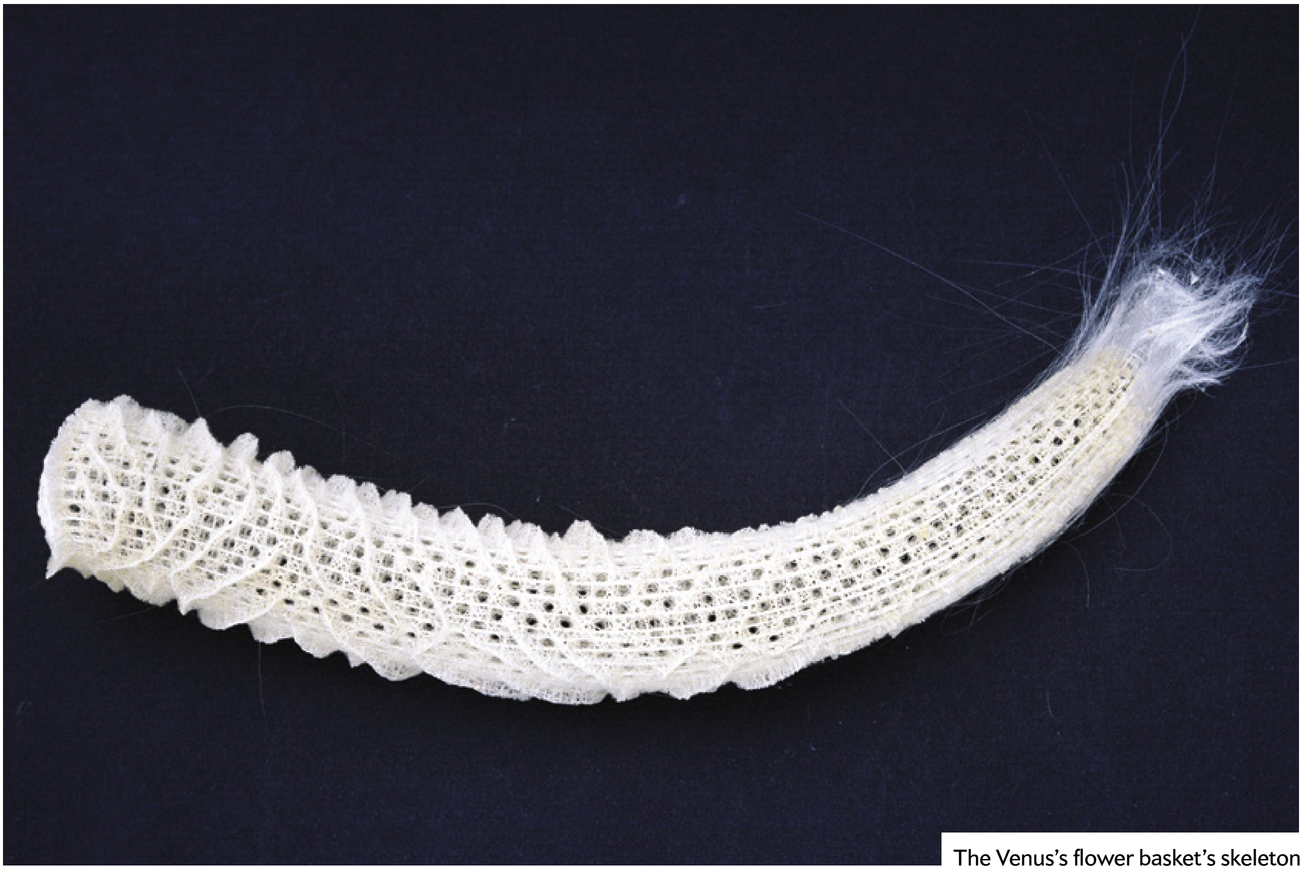
"We know that narrative has the power to transport us to another world," says Guilherme Brockington, who studies emotions and learning at Brazil's Federal University of ABC in São Paulo and was lead author on the new paper, published in the *Proceedings of the National Academy of Sciences USA*. Earlier research suggested that stories help children process and regulate their emotions—but this was mostly conducted in a laboratory, with subjects answering questions while lying inside functional MRI machines. "There are few studies on physiological and psychological effects of storytelling" in a more commonplace hospital setting, Brockington says.

So investigators working in several Brazilian hospitals split a total of 81 patients ages four to 11 into two groups, matching them with storytellers who had a decade of hospital experience. In one group, the storyteller led each child in playing a riddle game. In the other, youngsters chose books and listened as the storyteller read them aloud. Before and after these sessions, the researchers took saliva samples from each child, then asked them to report their pain levels and conducted a free-association word quiz.

Children in both groups benefited measurably from the interactions; they showed lower levels of the stress-related hormone cortisol and higher levels of oxytocin, which is often described as a feel-good hormone and is associated with empathy. Yet kids in the storytelling group benefited significantly more: their cortisol levels were a quarter of those in the riddle group, and their oxytocin levels were nearly twice as high. Those who heard stories also reported pain levels dropping almost twice as much as those in the riddle group, and they used more positive words to describe their hospital stay.

The study demonstrates that playing games or simply interacting with someone can relax kids and improve their outlook—but that hearing stories has an especially dramatic effect. The researchers "really tried to control the social interaction component of the storyteller, which I think was key," says Raymond Mar, a psychologist at York University in Canada who studies the effects of storytelling but was not involved in the new research.

Next, the investigators plan to study how long these effects last, along with storytelling's potential benefits to kids with particular illnesses such as cancer. For now Brockington says the results indicate storytelling is a low-cost and extremely efficient way to help improve health outcomes in a variety of settings. Mar agrees. "It's very promising and scalable," he says, "and possibly generalizable." —*Susan Cosier*



The Venus's flower basket's skeleton

FLUID DYNAMICS

Sea Sponges' Secrets

A romantic sponge holds engineering insights

Although their exteriors are made from intricately woven glass fibers, Venus's flower basket sponges are better known for something often found inside them: a breeding pair of shrimp that becomes trapped within the sponge's lava-lamp-shaped body and goes on to live there symbiotically. This romantic biology is the reason the deep-sea sponges are presented as wedding gifts in Japan—and it is also why a team of engineers became curious about how water passes through the sponges, helping their captives thrive.

The team theorized that the sponges' eye-catching patterns of ridges and holes altered the flow of water in and around the organisms. But an underwater experiment to pinpoint the effect of each structural attribute would have been logistically impossible. Instead the team ran a series of simulations, developed over the course of a decade, on one of Italy's highest-powered supercomputers. "I think this represents simulation at its best—something that you cannot do by experiment," says Sauro Succi, a senior research executive at the Italian Institute of Technology in Rome and co-author of the new study, published in *Nature*.

The researchers built a virtual three-dimensional model based on measurements of real sponges. Next they simulated billions of individual particles passing through it, with and without the ridges and holes. They discovered that the organism's porous lattice structure reduces drag from the flow of the water, and the ridges temper the water's force and create tiny vortices inside the sponge. These swirls make it easier for the sponge's eggs and sperm to mix while allowing the sponge—and the shrimp within—to feed more efficiently.

According to study lead author Giacomo Falcucci of the University of Rome Tor Vergata, this "twofold benefit" of durability and fertility surprised the team because evolutionary adaptations to boost breeding success often harm an organism in other departments. A peacock's attractive but heavy tail is one example of such a trade-off.

"It is really cool to see a study like this show that this complex morphology does really have [intriguing] implications for fluid dynamics," says Laura Miller, a mathematician and biomedical engineer at Arizona State University who was not involved with the research but authored an accompanying commentary in *Nature*.

In future research, this simulation method can be applied to other organisms whose fluid dynamics have never been minutely studied—Miller suggests a coral reef's intricate architecture could be one target. Plus, Venus's flower baskets have already inspired biomaterials, including a 3-D-printed grid that sustained more load without buckling than current bridges' lattice structures. By understanding the sponge's flow properties as well, the coauthors say they hope drag-reducing design principles could enhance tomorrow's skyscrapers, submarines and spaceships.

—Maddie Bender

Agefotostock *Alamy Stock Photo*


The Silent Extinction
Giraffe populations have declined **40%** in the last 30 years.
Our mission is to save giraffes from extinction so they can live freely and safely in the woodlands and savannas of their native Africa.
SAVE GIRAFFES NOW
DONATE NOW!
100% of your donation goes to the on-the-ground projects in Africa to help save giraffe from extinction.
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Photo by Guadalupe Laiz

Michael H. Levin is an environmental lawyer, solar energy developer and writer whose work has appeared on stage and in numerous publications. His poetry collections include *Watered Colors* (Poetica, 2014), *Man Overboard* (Finishing Line, 2018) and *Falcons* (Finishing Line, 2020). More of his writing is available at www.michaellevinpoetry.com

Jean-Pierre Bouchard *Getty Images*

EARTH'S ACCIDENTS (Over Wadi Qumran)

The Dead Sea scrolls were mostly saved
by bribe and threat: unmindful finders
re-interred the rest in hopes of
gain. It vanished or decayed.

A trooper in the Greek campaign
blown by Wehrmacht mortars down
a limestone chute, glimpsed there a lettered
chest—lost masterworks? new graphs

by Euclid or his heirs, perhaps. Never
reclaimed: the next rounds covered it
up again. Fountains of blazing
loam, then forced retreat—the blasted

ground left no remains of site-map
to be guessed. Great Aztec wheels;
Lascaux red bulls; dried funeral garlands
of Neanderthals: all brought to

light by restless chance—a dropped hoe
or a wandering goat. Vast evidence
unknown, we stand on ranks
of shoulders buried deep in earth

a fragmentary tune, made by the
breeze against a bone protruding
from a crumbled canyon wall.

Claudia Wallis is an award-winning science journalist whose work has appeared in the *New York Times, Time, Fortune* and the *New Republic.* She was science editor at *Time* and managing editor of *Scientific American Mind.*

When Health Takes a Tumble

Falls among the elderly are a top cause of death. Here's how to reduce the risk

By Claudia Wallis

In the senior community where my mom lives, death is a frequent visitor. When we talk about a recent loss, the story is often the same: her neighbor fell, and things got worse from there. Falls are the seventh-leading cause of death for adults aged 65 and older in the U.S., and their prevalence has jumped more than 30 percent in recent years, according to a 2018 report from the U.S. Centers for Disease Control and Prevention. Even when a spill doesn't cause serious injuries, it can be the beginning of the end for elderly adults, explains Patricia Dykes, who studies fall prevention at Brigham and Women's Hospital in Boston. "They become afraid to move. They'll think, 'Maybe I shouldn't walk so much.' Then they get weaker, and their balance gets poorer." This starts a spiral of more falls, increased injuries and worsening health. "Fear of falling prevents older people from doing the things that would prevent falls," she says.

There are likely many reasons for the rise in fall-related deaths. For one thing, more people are surviving heart disease, cancer and strokes and living into their 80s and 90s with impairments and chronic conditions that make them unsteady, says epidemiologist Elizabeth Burns of the CDC, who co-authored the 2018 report. "We also know that Americans use more medications than they used to," she says. Polypharmacy—taking four or more medications—increases the chance of falling. So does taking a drug that impacts the central nervous system, such as an opioid or antidepressant. Age-related changes in eyesight, cognition, muscle strength and balance also raise risk.

But experts insist that falling is not inevitable. Targeted exercises, modified drug regimens and fixing vision problems can reduce the risk. New technology may help, including smartphone apps that analyze gait, as well as AI tools that alert busy health-care providers to fall risks among their patients.

Probably the single most important thing an individual can do is to work on lower body strength, balance and gait. "Just like you need to eat every day, you need to exercise every day," Dykes says. The Otago exercise program, developed in New Zealand, has reduced falls by 35 percent among high-risk elderly when overseen by physical therapists. Many studies have looked at combining exercise programs with other changes, such as cutting back on certain medications and reducing household hazards. A 2018 review of 62 studies found that, on average, such multifaceted approaches cut the rate of falls by 23 percent.

Such results can be hard to achieve in the messy real world, however. Researchers had high hopes for the STRIDE study, which tracked 5,451 people aged 70 or older at 86 primary care practices across the U.S. All participants were at risk for falling. Half agreed to target one to three specific risk factors, whereas half were given basic information about preventing falls. But the results, published in 2020, showed no significant difference between the groups. Dykes, who was a co-author, says people may have avoided selecting factors that would have mattered most. For instance, "a lot of older people don't want to take away scatter rugs [a tripping hazard] or add grab bars in the shower and next to the toilet. They want their house to look like a home." With medications, it takes time and patience to persuade a patient to stop a drug they may have relied on for years. Some drugs that raise the odds of falling are used for conditions that impact fall risk if left untreated. "It makes for complicated decision-making for doctors," Burns says.

Given such challenges, several new efforts focus on offering better support to health-care providers. The CDC's STEADI program, for instance, gives doctors a suite of tools to identify and reduce fall risks among patients. In a large study in New York State, it cut the chances of a fall-related hospitalization by 40 percent. Dykes and her colleagues are now testing Web-based tools that scan patient electronic health records for fall risk factors and use algorithms to suggest remedies.

Technology can also help raise a person's own awareness of potential problems. Apple is about to introduce a "walking steadiness" rating to its iPhone Health app. It measures stability based on walking speed, step length, step symmetry, and an indicator of shuffling. Users with low ratings can access Otago-based exercise videos and other tools. As long as it doesn't scare users into retreating to their couches, the app and similar tools could help put more folks on a safer footing. SA

Illustration by Fatinha Ramos

MATHEMATICS

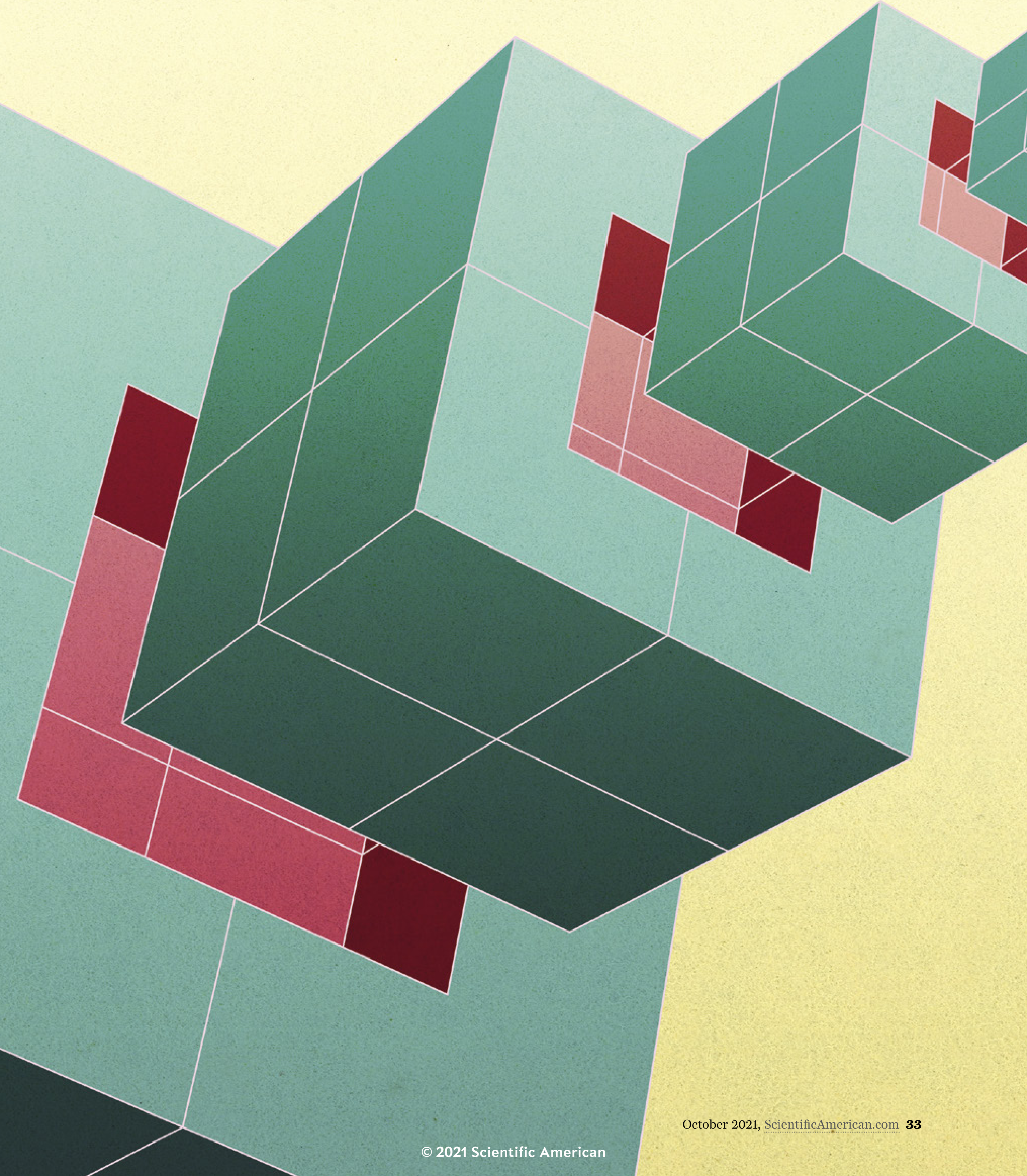
Infinite Math

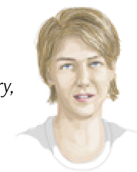
Mathematicians have expanded category theory into infinite dimensions, enabling new connections among sophisticated mathematical concepts

By Emily Riehl

Title illustration by Eric Petersen

Schematics by Matteo Farinella





Emily Riehl is a mathematician at Johns Hopkins University, where she works on category theory and the foundations of infinity categories. Her book *Elements of ∞-Category Theory,* co-authored with Dominic Verity, will be published in 2022 by Cambridge University Press.

ON A CRISP FALL NEW ENGLAND DAY DURING MY JUNIOR YEAR OF COLLEGE, I WAS walking past a subway entrance when a math problem caught my eye. A man was standing near a few brainteasers he had scribbled on the wall, one of which asked for the construction, with an imaginary straightedge and compass, of a cube with a volume twice that of a different, given cube.

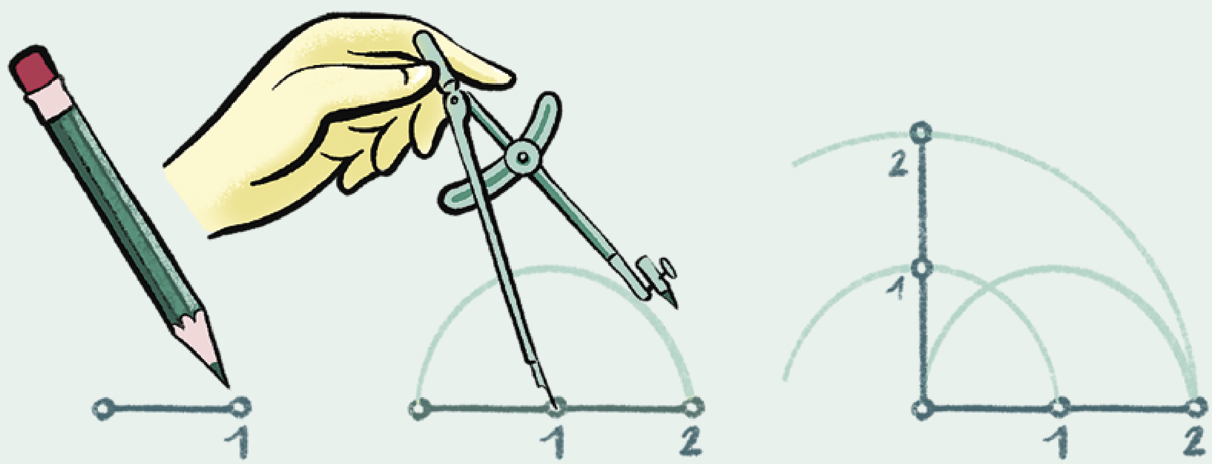
This stopped me in my tracks. I had seen this problem before. In fact, the challenge is more than two millennia old, attributed to Plato by way of Plutarch. A straightedge can be used to extend a line segment in any direction, and a compass can be used to draw a circle with any radius from the chosen center. The catch for this particular puzzle is that any points or lengths appearing in the final drawing must have been either present at the start or constructable from previously provided information.

To double a cube's volume, you start with its side length. Here that value might as well be 1 because it is the only unit of measurement given. To construct the larger cube, you have to figure out a way to draw one of its sides with the new required length, which is $\sqrt[3]{2}$ (the cube root of two), using just the straightedge and compass as tools.

It is a tough problem. For more than 2,000 years no one managed to solve it. Finally, in 1837, Pierre Laurent Wantzel explained why no one had succeeded by proving that it was impossible. His proof used cutting-edge mathematics of the time, the foundations of which were laid by his French contemporary Évariste Galois, who died at 20 in a duel that may have involved an unhappy love affair. At the ripe old age of 20 myself, I had achieved considerably less impressive mathematical accomplishments, but I at least understood Wantzel's proof.

Here is the idea: Given a point as the origin and a length of distance 1, it is relatively straightforward to use the straightedge and compass to construct all points on a number line whose coordinates are rational numbers (ignoring, as mathematicians tend to do, the impossibility of actually plotting infinitely many points in only a finite amount of time).

SUBWAY BRAINTEASER



Step 1: Use the compass to mark a distance of 1.

Step 2: Use the compass at the same radius to mark a distance of 2.

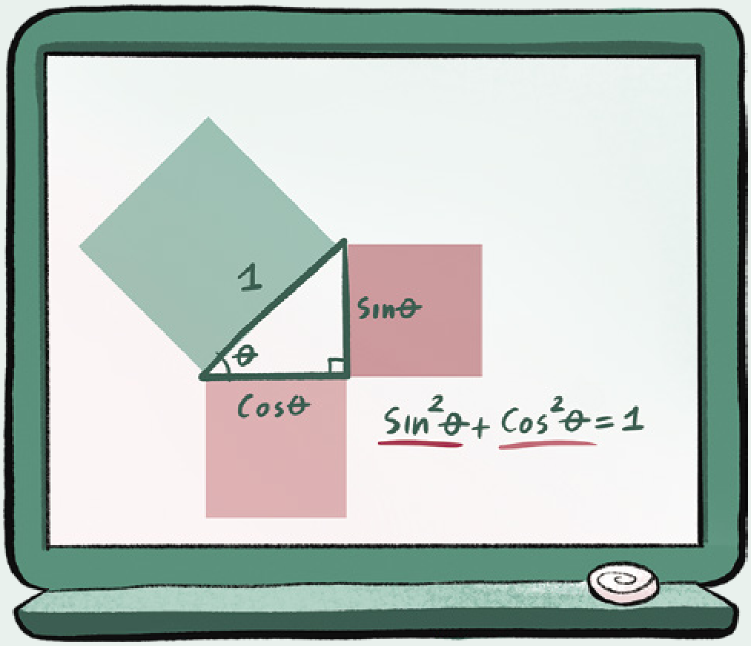
Step 3: Construct a perpendicular line through the point zero using the compass to determine perpendicularity and mark points on this axis using the method in steps 1 and 2.

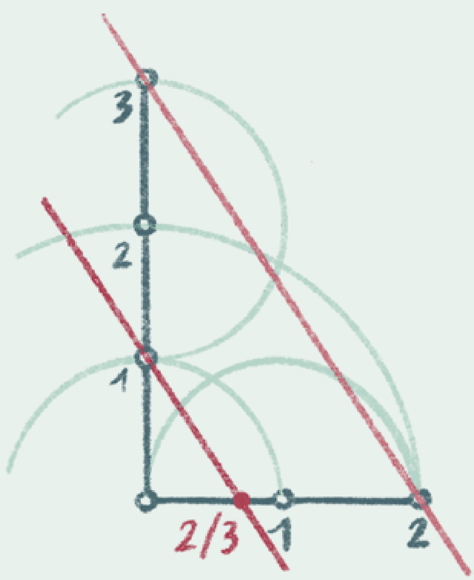
Wantzel showed that if one uses only these tools, each newly constructed point must be a solution to a quadratic polynomial equation $ax^2 + bx + c = 0$ whose coefficients *a, b* and *c* are among the previously constructed points. In contrast, the point $\sqrt[3]{2}$ is a solution to the cubic polynomial $x^3 - 2 = 0$, and Galois's theory of "field extensions" proves decisively that you can never get the solution to an irreducible cubic polynomial by solving quadratic equations, essentially because no power of 2 evenly divides the number 3.

Armed with these facts, I could not restrain myself from engaging with the man on the street. Predictably, my attempt to explain how I knew his problem could not be solved did not really go anywhere. Instead he claimed that my education had left me closed-minded and unable to "think outside the box." Eventually my girlfriend managed to extricate me from the argument, and we continued on our way.

But an interesting question remains: How was I, a still-wet-behind-the-ears undergraduate in my third year of university study, able to learn to comfortably manipulate abstract number systems such as Galois's fields in just a few short weeks? This material came at the end of a course filled with symmetry groups, polynomial rings and related treasures that would have blown the minds of mathematical giants such as Isaac Newton, Gottfried Leibniz, Leonhard Euler and Carl Friedrich Gauss. How is it that mathematicians can quickly teach every new generation of undergraduates discoveries that astonished the previous generation's experts?

PYTHAGOREAN THEOREM





Step 4: Use a straightedge to draw a line through point 2 on the horizontal axis and point 3 on the vertical axis. Use compass to make two perpendicular lines to construct a parallel line between the vertical point 1 and the position of 2/3 on the horizontal axis.

Part of the answer has to do with recent developments in mathematics that provide a "birds-eye view" of the field through ever increasing levels of abstraction. Category theory is a branch of mathematics that explains how distinct mathematical objects can be considered "the same." Its fundamental theorem tells us that any mathematical object, no matter how complex, is entirely determined by its relationships to similar objects. Through category theory, we teach young mathematicians the latest ideas by using general rules that apply broadly to categories across mathematics rather than drilling down to individual laws that apply only in a single area.

As mathematics continues to evolve, mathematicians' sense of when two things are "the same" has expanded. In the past few decades many other researchers and I have been working on an extension of category theory to make sense of this new expanded notion of uniqueness. These new categories, called infinity categories (∞-categories), broaden category theory to infinite dimensions. The language of ∞-categories gives mathematicians powerful tools to study problems in which relations between objects are too nuanced to be defined in traditional categories. The perspective of "zooming out to infinity" offers a novel way to think about old concepts and a path toward the discovery of new ones.

CATEGORIES

LIKE MANY other mathematicians I know, I was drawn into the subject partly because of my poor memory. This confounds many people who remember high school mathematics as rife with formulas to memorize—the trigonometric identities come to mind. But I took comfort in the fact that the most commonly used formulas could be re-derived from $\sin^2\theta + \cos^2\theta = 1$, which itself has an elegant geometric explanation: it is an application of the Pythagorean theorem to a right triangle with a hypotenuse of length 1 and an acute angle of θ degrees.

This utopian vision of mathematics where everything just "makes sense" and nothing needs to be memorized falls apart to some extent at the university level. At that point students get to know the zoo of mathematical objects that have been conjured into existence in the past few centuries. "Groups," "rings" and "fields" belong

As mathematics continues to evolve, mathematicians' sense of when two things are "the same" has expanded.

to an area of mathematics known as algebra, a word derived from a ninth-century book by Persian mathematician and astronomer Muhammad ibn Musa al-Khwarizmi, the title of which is sometimes translated as *The Science of Restoring and Balancing.* Over the next millennium, algebra evolved from the study of the nature of solutions to polynomial equations to the study of abstract number systems. Because no real number x satisfies the equation $x^2 + 1 = 0$, mathematicians built a new number system—now known as the complex numbers—by adding an imaginary number i and imposing the stipulation that $i^2 + 1 = 0$.

Algebra is only one of the subjects in a mathematics undergraduate's curriculum. Other cornerstones include topology—the abstract study of space—and analysis, which begins with a rigorous treatment of the calculus of real functions before branching into the more exotic terrains of probability spaces and random variables and complex manifolds and holomorphic functions. How is a student supposed to make sense of it all?

A paradoxical idea in mathematics is that of simplification through abstraction. As Eugenia Cheng puts it in *The Art of Logic in an Illogical World,* "a powerful aspect of abstraction is that many different situations become the same when you forget some details." Modern algebra was created in the early 20th century when mathematicians decided to unify their studies of the many examples of algebraic structure that arose in the consideration of solutions to polynomial equations or of configurations of figures in the plane. To connect investigations of these structures, researchers identified "axioms" that describe their common properties. Groups, rings and fields were introduced to the mathematical universe, along with the idea that a mathematical object could be described in terms of the properties it has and explored "abstractly," independently of the scaffolding of particular examples or constructions.

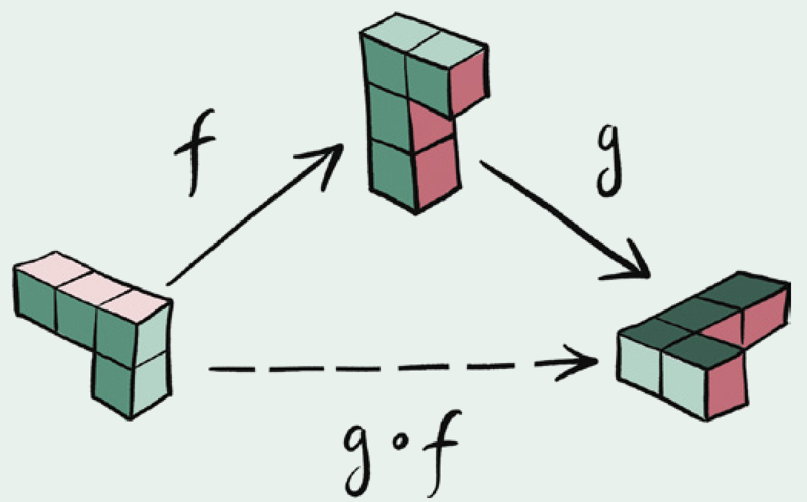
John Horton Conway famously pondered the curious ontology of mathematical things: "There's no doubt that they do exist but you can't poke and prod them except by thinking about them. It's quite astonishing and I still don't understand it, despite having been a mathematician all my life. How can things be there without actually being there?"

But this world of mathematical objects that can exist without actually being there created a problem: Such a world is vastly too large for any person to comprehend. Even within algebra, there are just too many mathematical things to study for there to be time to make sense of them all. Around the turn of the 20th century, mathematicians began to investigate so-called universal algebra, referring to a "set," which could be a collection of symmetries, of numbers in some system or something else entirely, together with various operations—for instance, addition and multiplication—satisfying a list of relevant axioms such as associativity, commutativity or distributivity. By making different choices—Is an operation partially or totally defined? Is it invertible?—one arrives at the standard algebraic structures: the groups, rings and fields. But the subject is not constrained by these choices, which represent a vanishingly small portion of an infinite array of possibilities.

The proliferation of new abstract mathematical objects brings its own complexity. One way to simplify is to introduce a further level of abstraction where, astonishingly, we can prove theorems about a wide variety of mathematical objects simultaneously without specifying exactly what kinds of objects we are talking about.

Category theory, which was created in the 1940s by Samuel Eilenberg and Saunders Mac Lane, does just this. Although it was originally introduced to give a rigorous definition of the colloquial term "natural equivalence," it also offers a way to think universally about universal algebra and other areas of mathematics as well. With Eilenberg and Mac Lane's language, we can now understand that every variety of mathematical object belongs to its own *category,* which is a specified collection of objects together with a set of transformations depicted as arrows between the objects. For example, in linear algebra one studies abstract vector spaces such as three-dimensional Euclidean space. The corresponding transformations in this case are called linear transformations, and each must have a specified source and target vector space indicating which kinds of vectors arise as inputs and outputs. Like functions, the transformations in a category can be "composed," meaning you can apply one transformation to the results of another transformation. For any pair of transformations $f: A \to B$ (read as "f is a transformation from A to B") and $g: B \to C$, the category specifies a unique composite transformation, written as $g \circ f: A \to C$ (read as "g composed f is a transformation from A to C"). Finally, this composition law is associative, meaning $h \circ (g \circ f) = (h \circ g) \circ f$.

COMPOSITE TRANSFORMATION



It is also unital: each object B has an "identity transformation" commonly denoted by 1_B with the property that $g \circ 1_B = g$ and $1_B \circ f = f$ for any transformations g and f whose source and target, respectively, equal B.

How do categories help the hapless undergraduate confronted with too many mathematical objects and not enough time to learn about them all? Any class of structures you can define in universal algebra may be distinct from all others, but the categories these objects inhabit are very similar in ways that can be expressed precisely through categorical language.

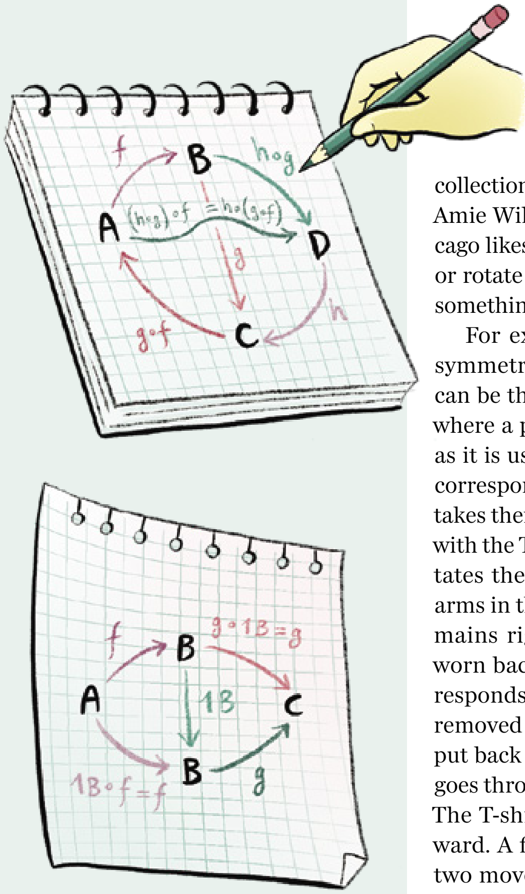
With sufficient experience, mathematicians can know what to expect when they encounter a new type of algebraic structure. This idea is reflected in modern textbooks on the subject that develop the theories of groups, rings and vector spaces in series, essentially because the theories are parallel. There are other, looser analogies among these categories and the ones students encounter in topology or analysis courses, and these similarities enable them to absorb the new material more quickly. Such patterns allow students to spend more time exploring the special topics that distinguish individual mathematical subdisciplines—although research advances in mathematics are often inspired by new and surprising analogies between previously unconnected areas.

SYMMETRIES

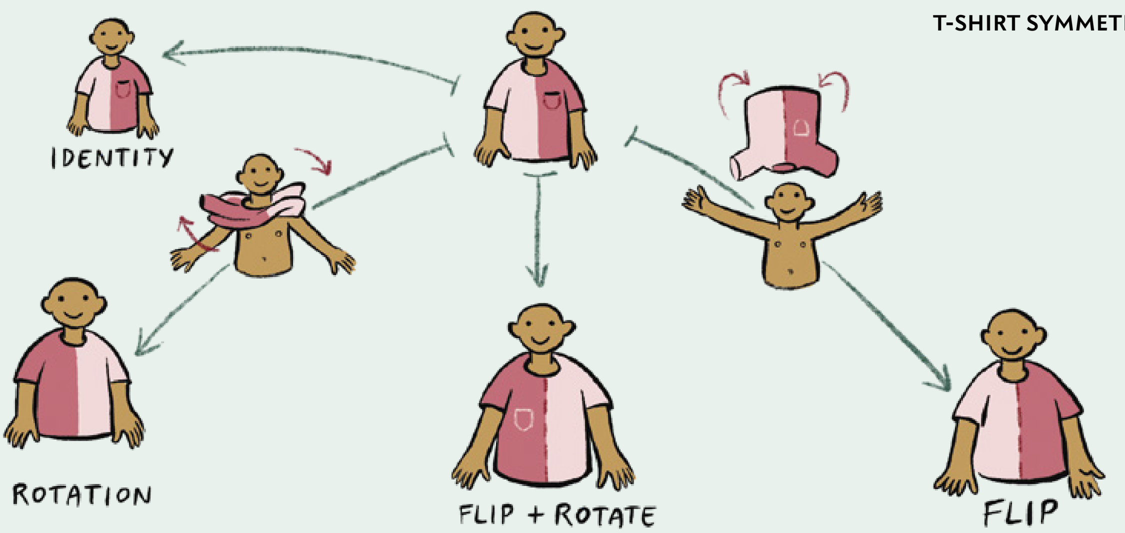
THE CASCADING LEVELS of abstraction, from concrete mathematical structures to axiomatic systems and then beyond to the general objects that belong to categories, present a new challenge: it is no longer very clear what it means to say that one thing is "the same" as another thing. Consider, for instance, a group, which in math is an abstract collection of symmetries whose elements Amie Wilkinson of the University of Chicago likes to describe as "moves" that flip or rotate an object before settling it into something like the original position.

For example, we might explore the symmetries of a T-shirt. One symmetry can be thought of as the "identity move," where a person simply wears the T-shirt as it is usually worn. Another symmetry corresponds to a move where the wearer takes their arms out of the arm holes and, with the T-shirt still around their neck, rotates the shirt 180 degrees to put their arms in the opposite holes: the T-shirt remains right-side out but is now being worn backward. Another symmetry corresponds to a move where the T-shirt is removed entirely, flipped inside out and put back on in such a way that each arm goes through the hole it was originally in. The T-shirt is now inside out and backward. A final symmetry combines these two moves: atypically for groups, these moves can be performed in any order without changing the end result. Each of these four moves counts as a "symmetry" because they result in the shirt being worn in essentially the same way as when you started.

COMPOSITIONS ARE ASSOCIATIVE AND UNITAL



T-SHIRT SYMMETRIES



Another group is the “mattress-flipping group,” which describes the symmetries of a mattress. In addition to the identity move, which applies when the mattress is left in its original position, a person can move the mattress by rotating it top to bottom, flipping back to front or performing both moves in sequence. (Mattresses typically are not square, but if they were, there would be more symmetries than described here.) Although a T-shirt does not have much to do with a mattress, there is a sense in which the two symmetry groups have the same “shape.” First, both groups of symmetries have the same number of moves (in this case, four), and, crucially, you can pair each move in the T-shirt group with a move in the mattress-flipping group such that the compositions of corresponding moves also correspond. In other words, you can match up moves from the two groups (match the identity with the identity, the flip with the flip, the rotation with the rotation, and so on). Second, if you take two moves from one group and perform them in sequence, the final position will match with the end result of performing the corresponding moves from the other group in sequence. In technical terms, these groups are connected by an “isomorphism,” a term whose etymology—from the Greek *isos,* meaning “equal,” and *morphe,* meaning “form”—indicates its meaning.

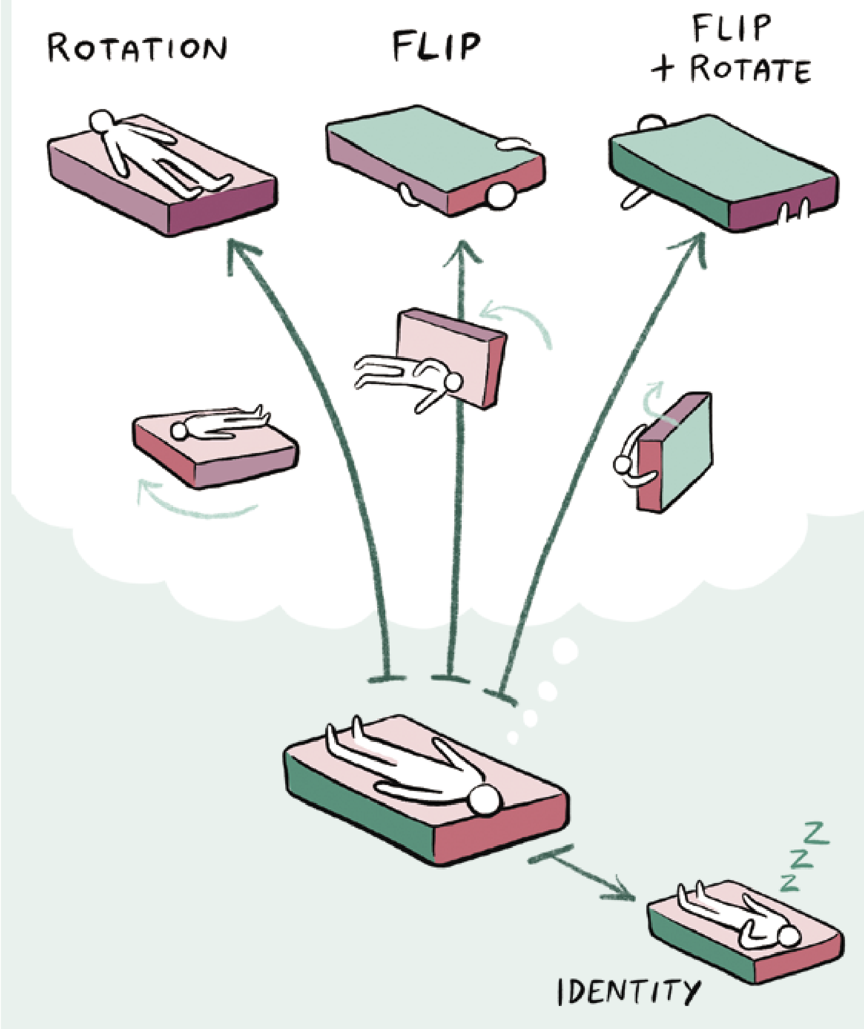
We can define the notion of isomorphism in any category, which allows us to transport this concept between mathematical contexts. An isomorphism between two objects A and B in a category is given by a pair of transformations, $f: A \to B$ and $g: B \to A$, with the property that the composites $g \circ f$ and $f \circ g$ equal the respective identities 1_A and 1_B. In the category of topological spaces, the categorical notion of isomorphism is represented by an inverse pair of continuous functions. For instance, there is a continuous deformation that would allow you to convert an unbaked doughnut into a shape like a coffee mug: the doughnut hole becomes the handle, and the cup is formed by a depression you make with your thumb. (For the deformation to be continuous, you must do this without tearing the dough, which is why the doughnut should not be baked before the experiment is attempted.)

This example inspired the joke that a topologist cannot tell the difference between a coffee mug and a doughnut: as abstract spaces, these objects are the same. In practice, many topologists are arguably much less observant than this because it is common to adopt a more flexible convention concerning situations when two spaces are “the same,” identifying any two spaces that are merely “homotopy-equivalent.” This term refers to the notion of isomorphism in the more exotic homotopy category of spaces. A homotopy equivalence is another type of continuous deformation, but in this case, you can identify distinct points. For instance, imagine starting with a pair of pants and then shrinking the lengths of the legs until you are left with a G-string, another “space” with the same fundamental topological structure—there are still two holes for legs—even though the original two-dimensional garment has been shrunk down to a one-dimensional bit of string.

Another homotopy equivalence collaps-

How is it that mathematicians can quickly teach every new generation of undergraduates discoveries that astonished the previous generation’s experts?

MATTRESS SYMMETRIES



es the infinite expanse of three-dimensional Euclidean space down to a single point via a "reverse big bang" in which each point flies back to its origin, with the speed of this motion increasing with the distance from the location of the initial big bang.

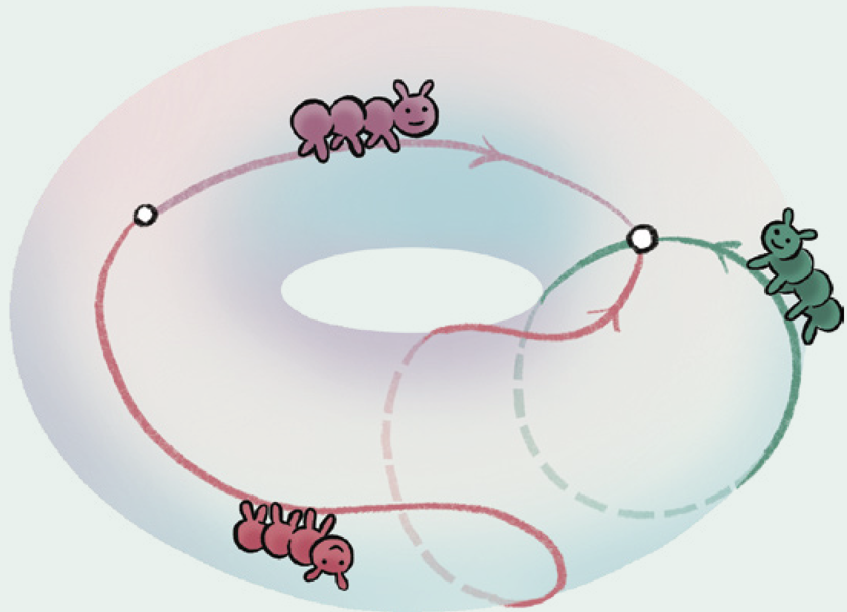
The intuition that we can substitute isomorphic things for one another without fundamentally changing the nature of a construction or an argument is so strong that in fact category theorists have redefined the word "the" to mean something closer to "a" in colloquial English. For example, there is a concept known as the disjoint union of two sets A and B. Like the ordinary union, the disjoint union $A \sqcup B$ has a copy of every element of A and a copy of every element of B. Unlike in the ordinary union, however, if A and B have an element in common, then the disjoint union $A \sqcup B$ has two copies of that element, one of which somehow remembers that it came from A, and the other somehow remembers it came from B.

There are many different ways to construct the disjoint union using the axioms of set theory, which will not produce exactly the same set but will, necessarily, produce isomorphic ones. Rather than wasting time arguing about which construction is the most canonical, it is more convenient to just sweep this ambiguity under the rug and refer to "the" disjoint union when one means to consider any particular set that satisfies the desired universal property. In another example, mathematicians refer to both the T-shirt symmetry group and the mattress-flipping group as "the Klein four-group."

INFINITE-DIMENSIONAL CATEGORIES

AN OFT-TOLD STORY about the origin of the fundamental theorem of category theory is that a young mathematician named Nobuo Yoneda described a "lemma," or helper theorem, to Mac Lane at the Gare du Nord train station in Paris in 1954. Yoneda began explaining the lemma on the platform and continued it on the train before it departed the station. The consequence of this lemma is that any object in any category is entirely determined by its relation to the other objects in the category as encoded by the transformations to or from this object. So we can characterize a topological space X by probing it with continuous functions $f: T \rightarrow X$ mapping out other spaces T. For instance, the points of the space X correspond to continuous functions $x: * \rightarrow X$, whose domain is a space with a single point. We can answer the question of whether the space X is connected or disconnected by considering mappings $p: I \rightarrow X$, whose domain is an interval $I = [0,1]$. Each such mapping defines a parameterized "path" in the space X from the point $p(0)$ to the point $p(1)$, which can be thought of as a possible trajectory an ant might take when walking around the space X.

ANT PATHS IN THE SPACE X



We can use the points and paths of a space to translate problems of topology into problems of algebra: each topological space X has an associated category $\pi_1 X$ called the "fundamental groupoid" of X. The objects of this category are the points of the space, and the transformations are paths. If one path can be deformed into another in the space while its end points remain fixed, the two paths define the same transformation. These deformations, which are technically called homotopies, are necessary for the composition of paths to define an associative operation, as is required by a category.

A key advantage of the fundamental groupoid construction is that it is "functorial," meaning that a continuous function $f: X \rightarrow Y$ between topological spaces gives rise to a corresponding transformation $\pi_1 f: \pi_1 X \rightarrow \pi_1 Y$ between the fundamental groupoids. This assignment respects composition and identities, mean-

A Quick Guide to Modern Math Terminology

Category: a specified collection of objects and transformations between them, with a composition rule

Composition: to apply one transformation to the results of another

Identity: a transformation from an object to itself that does not change it in any way

Symmetry: an invertible transformation from an object to itself

Isomorphism: a structural notion of "sameness" that may exist between a pair of objects in a category

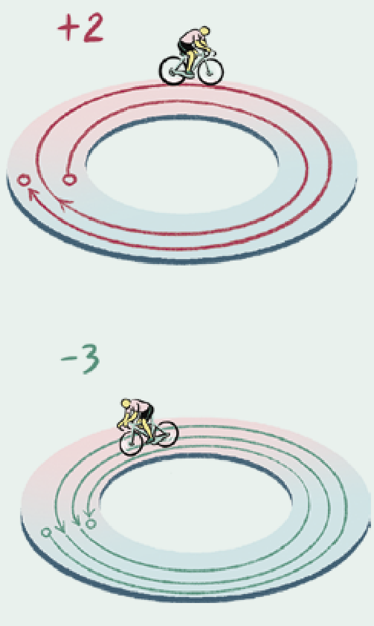
Fundamental groupoid: a category whose objects are the points in a space and whose transformations are paths between them, up to homotopy

Homotopy: a "path between paths" defined by a continuous deformation from one path to another

Infinity category: an infinite-dimensional analogue of a category, which adds higher-dimensional transformations and weakens the composition rule

Fundamental infinity groupoid: an infinity category of points, paths, homotopies and higher homotopies in a space

THE FUNDAMENTAL GROUPOID OF A CIRCLE



ing $\pi_1(g \circ f) = \pi_1 g \circ \pi_1 f$ and $\pi_1(1_X) = 1_{\pi_1 X}$, respectively. These two properties, which collectively go by the name "functoriality," suggest that the fundamental group captures some essential information about topological spaces. In particular, if two spaces are not homotopy-equivalent, then their fundamental groupoids are necessarily inequivalent.

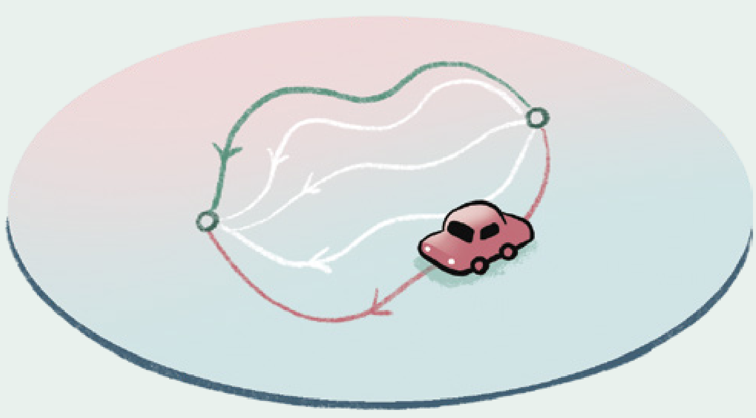
The fundamental groupoid is not a complete invariant, however. It can easily distinguish between a circle and the solid disk that circle bounds. In the fundamental groupoid of the circle, the different wiggling versions of a path between two points can be labeled by integers that record the number of times the trajectory winds around the circle and a + or − sign indicating, respectively, a clockwise or counterclockwise direction of transit. In contrast, in the fundamental groupoid of the disk, there is only one path up to homotopy between any pair of points. The fundamental groupoid of the space formed by the inflatable exterior of a beach ball, a sphere in topological terms, also has this description: there is a unique path up to homotopy between any two points.

The big problem with the fundamental groupoid is that points and paths do not detect the higher-dimensional structure of a space, because the point and interval are themselves zero- and one-dimensional, respectively. A solution is to also consider continuous functions from the two-dimensional disk, called homotopies, and "higher homotopies," defined by continuous functions from the solid three-dimensional ball and similarly for other balls in 4, 5, 6 or more dimensions.

It is natural to ask what kind of algebraic structure the points, paths, homotopies and higher homotopies in a space X form: this structure $\pi_\infty X$ ("pi infinity X"), referred to as the fundamental ∞-groupoid of X, defines an example of an ∞-category, an infinite-dimensional analogue of the categories first introduced by Eilenberg and Mac Lane. Like an ordinary category, an ∞-category has objects and transformations visualized as one-dimensional arrows, but it also contains "higher transformations" depicted by two-dimensional arrows, three-dimensional arrows, and so on. For example, in $\pi_\infty X$ the objects and arrows are the points and the paths—no longer considered up to wiggling—while the higher-dimensional transformations encode the higher homotopies. Like in an ordinary category, the arrows in any fixed dimension can be composed: if you have two arrows $f: X \to Y$ and $g: Y \to Z$, there must also be an arrow $g \circ f: X \to Z$. But there is a catch: in attempts to capture natural examples such as the fundamental ∞-groupoid of a space, the composition law must be weakened. For any composable pair of arrows, there must exist a composite arrow, but there is no longer a unique specified composite arrow.

This failure of uniqueness makes it challenging to define ∞-categories in the classical set-based foundations of mathematics because we can no longer think of composition as an operation resembling those appearing in universal algebra. Although ∞-categories are increasingly central to modern research in many areas of mathematics, from quantum field theory to algebraic geometry to algebraic topology, they are often considered "too hard" for all but specialists and are not featured regularly in curricula, even at the graduate level. Nevertheless, many others and I see ∞-categories as a revolutionary new direction that can enable mathematicians to dream of new connections that would otherwise have been impossible to rigorously state and prove.

THE FUNDAMENTAL GROUPOID OF A DISK



THE FUTURE HORIZON

HISTORICAL EXPERIENCE suggests, however, that the most exotic mathematics of today will eventually be thought of as easy enough to teach to mathematics undergraduates in the future. It is fun to speculate, as a researcher in ∞-category theory, about how this subject could be simplified. In this case, there is a linguistic trick—a supercharged version of the categorical "the"—that could make ∞-categories as easy for late 21st-century undergraduates to think about as ordinary categories are today. The key axiom in an ordinary category is the existence of a unique composite transformation $g \circ f: X \to Z$ for each composable pair of transformations $f: X \to Y$ and $g: Y \to Z$, chosen from all the elements of the set of transformations from X to Z. In contrast, in an ∞-category, there is a space of arrows leading from X to Z, which in the fundamental ∞-groupoid can be understood as a kind of "path space." The correct analogue of the uniqueness of composites in an ordinary category is the assertion that in an ∞-category, the space of composites is "contractable," meaning that each of its points can be continuously collapsed via a reverse big bang to a single point of origin.

Note that contractability does not imply that there is a unique composite: indeed, as we have seen in the fundamental ∞-groupoid, there can be a large number of composite paths. But contractability guarantees that any two composite paths are homotopic, any two homotopies relating two composite paths are connected by a higher homotopy, and so on.

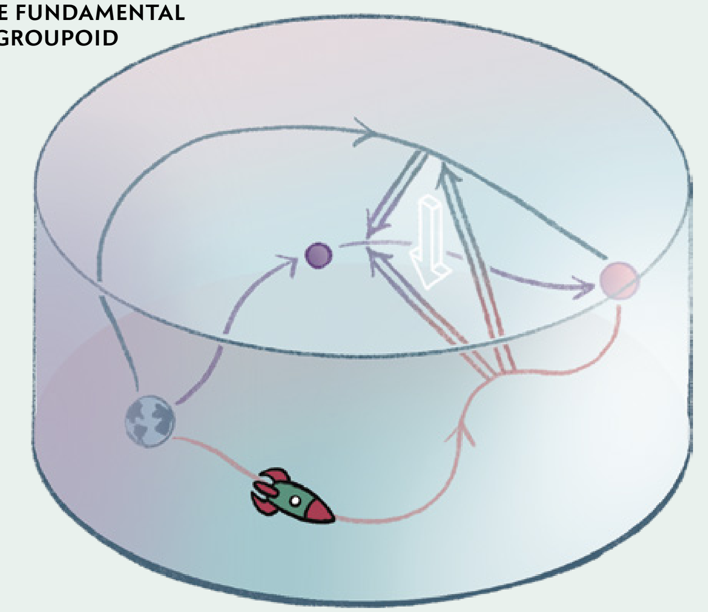
This idea of uniqueness as a type of contractability condition is a central one in a new foundation system for mathematics proposed by Vladimir Voevodsky and others. Mathematicians around the world are collaborating to develop new computer-based "proof assistants" that can check a formal proof of a mathematical result line by line. These proof assistants have a mechanism that mimics the common mathematical practice of transferring information about one thing to another thing that is understood to be the same via an explicit isomorphism or homotopy equivalence. In this case, the mechanism allows the user to transport a proof involving one point in a space along a path that connects it to any other point, giving a rigorous formulation of the topological notion of sameness.

In a 1974 essay, mathematician Michael Atiyah wrote, "The aim of theory really is, to a great extent, that of systematically organizing past experience in such a way that the next generation, our students and their students and so on will be able to absorb the essential aspects in as painless a way as possible, and this is the only way in which you can go on cumulatively building up any kind of scientific activity without eventually coming to a dead end." Category theory arguably plays this role in modern mathematics: if mathematics is the science of analogy, the study of patterns, then category theory is the study of patterns of mathematical thought—the "mathematics of mathematics," as Eugenia Cheng of the School of the Art Institute of Chicago has put it.

The reason that we can cover so much ground in an undergraduate course today is that our understanding of various mathematical concepts has been simplified through abstraction, which might be thought of as the process of stepping back from the specific problem being considered and taking a broader view of mathematics. A lot of fine details are invisible from this level—numerical approximations, for instance, or really anything having to do with numbers at all—but it is a remarkable fact that theorems in algebra, set theory, topology and algebraic geometry sometimes are true for the same underlying reason, and when this is the case, these proofs are expressed in the language of category theory.

What is on the horizon for the future? The emerging consensus in certain areas of mathematics is that the natural habitats of 21st-century mathematical objects are ∞-categories in the same way that 20th-century mathematical objects inhabit ordinary categories. The hope is that the dizzying tower of arrows in each dimension that one needs to do deep work in an ∞-category will at some point recede into the background of the collective mathematical subconscious, with each contractable space of choices collapsed down to a unique point. And one can only wonder: If this much progress was made during the 20th century, where will mathematics be at the end of the 21st? SA

THE FUNDAMENTAL ∞-GROUPOID



If mathematics is the science of analogy, the study of patterns, then category theory is the study of patterns of mathematical thought.

FROM OUR ARCHIVES

The Three-Body Problem. Richard Montgomery; August 2019.

scientificamerican.com/magazine/sa

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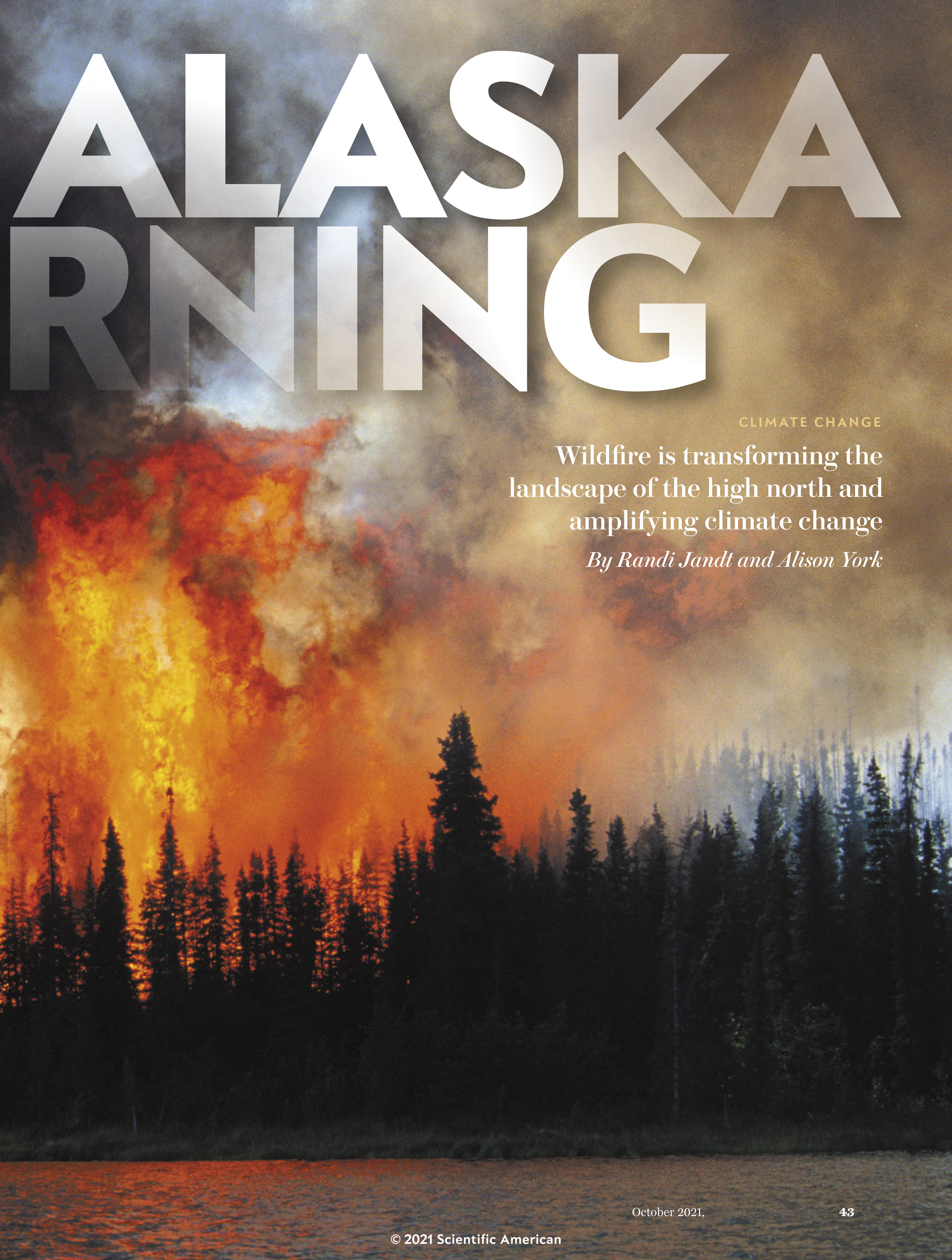
FIRE alongside Alaska's Skilak Lake was ignited by lightning, which is on the rise as Alaska warms.



ALASKA RNING

CLIMATE CHANGE

Wildfire is transforming the landscape of the high north and amplifying climate change

By Randi Jandt and Alison York

On June 5, 2019, lightning from an unusually early spring thunderstorm ignited a blaze deep inside the Kenai National Wildlife Refuge in south-central Alaska. High temperatures at the end of May had reversed a wet spring and quickly dried out the forest floor. The resulting Swan Lake Fire, about five miles northeast of Sterling, spread relentlessly for a month as the extraordinarily warm weather continued. By July 9 more than 99,000 acres had burned, and more than 400 people were fighting the flames. On August 17 high winds changed the fire's direction, causing numerous evacuations. The wind also downed power lines that sparked new fires, including the Deshka Landing Fire and the fast-moving McKinley Fire, which engulfed more than 130 homes, businesses and outbuildings. Fortunately, no one died.

The Swan Lake Fire burned until October, when overdue rains finally helped firefighters contain the conflagration, after 167,000 acres—261 square miles—had been charred. During the five-month blaze, troopers had to repeatedly close the Sterling Highway, the only major road in the area. Health officials issued public warnings about "unhealthy" or even "hazardous" smoky air filled with tiny particulates that can damage lungs on one third of all days in June, July and August in the south-central region, home to 60 percent of the state's population. Tourism-dependent businesses lost 20 percent of their seasonal revenue.

Winter snow and cold offered a reprieve, but in January 2020 a crew grooming snow machine trails reported smoke where the Deshka Landing Fire had been. When firefighters arrived, they found that the fire had never fully gone out. It had smoldered underground for four months and reemerged through the snow cover. As the state became warm and dry again in June, reports came in of smoke where the Swan Lake Fire had been. It had smoldered through eight months of winter and spring and reignited.

These so-called zombie fires—thought dead but reanimated—are flaring up as climate change makes the Alaska fire season hotter and longer. From 2005 to 2017, fire managers in Alaska and in Canada's Northwest Territories reported 48 zombie, or holdover, fires that survived the long winter. Rebecca Scholten, a remote-sensing specialist at Vrije Universiteit Amsterdam who works with Alaska fire managers, has discovered 20 more that were undocumented, by searching back through satellite imagery. The unusual phenomenon occurs across the high north, and it was responsible for extremely early blazes in northern Siberia in March 2020 and March 2021.

Zombie fires can recur because in northern ecosystems trees are not the only—or even the main—fuel. A thick, organic blanket of live and dead plant material covers the surface in the treeless tundra and the boreal forests just to their south. This dense, peaty layer, called duff, is the accumulation of each summer's dead surface moss and litter, its decomposition slowed by the low temperatures at these high latitudes. Duff can range in thickness from three to 20 inches (eight to 50 centimeters). It can accumulate for centuries, becoming increasingly compacted and dense with time.

The duff's surface is a green veneer made mostly of

Randi Jandt is a fire ecologist, wildlife biologist and occasional firefighter at the International Arctic Research Center and the Alaska Fire Science Consortium at the University of Alaska Fairbanks.

Alison York is a researcher at the International Arctic Research Center and is coordinator for the Alaska Fire Science Consortium.

SINKHOLES can form after fire consumes the insulating surface layer, exposing permafrost and ice wedges that thaw and slump, which happened here after the Anaktuvuk River Fire.

Design Pics, Inc. *Alamy Stock Photo (preceding pages);* Eric Miller *Bureau of Land Management's Alaska Fire Service (this page)*

DUFF that covers high-latitude forest floors can be up to 20 inches thick (*ruler*); zombie fires can smolder in that layer for an entire winter. Metal rods inserted into duff before fire can show how much is consumed by subsequent flames (*yellow sleeves*).

Randi Jandt

feather mosses, which do not have roots or a vascular system but instead draw moisture directly from the air. Their moisture content varies almost instantaneously with relative humidity; even after rain, the moss can dry enough within hours to burn. The longer, hotter, drier summers and shorter winters that climate change is bringing to the northern high latitudes are turning wide tracts of forest floor and trees into tinderboxes that lightning—or careless people—can readily ignite.

Wildfires across the high north are increasing in frequency and size. They are also transforming landscapes and ecosystems. In addition to being a fuel, duff is a remarkable insulator of underlying frozen ground—so much so that it has been keeping much of subsurface Alaska frozen since the Pleistocene epoch. Each half-inch of thickness keeps the underlying permafrost—ground that remains below freezing for two or more years—about 1 degree Fahrenheit (0.6 degree Celsius) cooler. But if enough duff burns off, the underlying permafrost thaws, turning parts of Alaska into softening, slumping ground. Trees rooted in this thawing ground can tilt at all angles, like haphazard Leaning Towers of Pisa.

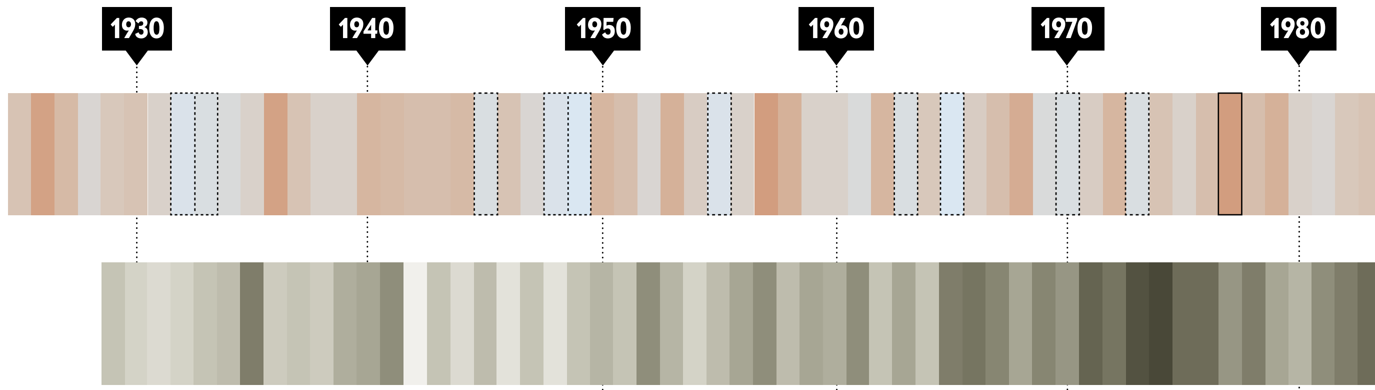
Extensive wildfire is accelerating climate change, too. Large fires throw a stunning amount of carbon dioxide into the atmosphere. Most of it comes from the duff, not the trees. The thick duff layers across high latitudes store 30 to 40 percent of all the soil carbon on Earth. In 2015 severe wildfires in interior Alaska burned 5.1 million acres, releasing about nine million metric tons of carbon from standing vegetation—and 154 million tons from the duff, according to Christopher Potter of NASA's Earth Sciences Division. (That calculation includes carbon lost to decomposition and erosion for two subsequent years.) The total amount of CO_2 is equal to that emitted by all of California's cars and trucks in 2017. As more ground thaws, ice in the lower layers of duff melts and drains away, drying the duff farther down, making it more ready to burn deeply. This feedback loop most likely will expand the acres burned, aggravate health for millions of people and make the climate change faster than ever. Feedbacks may even convert the entire region from one that absorbs more carbon than it emits to one that emits more carbon than it absorbs.

WET YET DRY

PEOPLE TEND TO THINK of Alaska as snowy and unlikely to burn, yet much of the state, especially the interior, has a continental climate with long, cold winters but warm and relatively dry summers. If you fly over interior Alaska in the summer, you will see a vast green landscape of forests, meadows and lakes. The lush appearance is deceiving because the region gets very little precipitation. Slow, sustained melting of snow in spring and thawing of the "active layer" immediately below the duff that refreezes each winter provide water for greening, but the duff surface can become desert-dry with a week or two of warm weather.

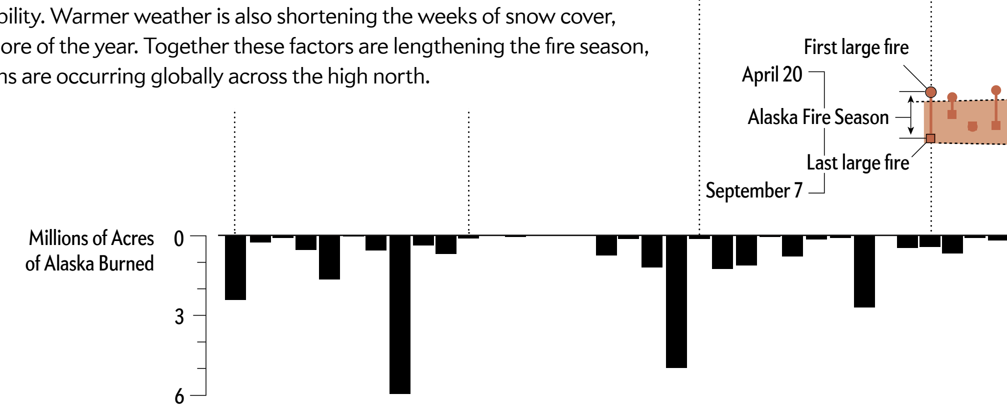
Boreal forests are Earth's largest woodland biome, comprising 30 percent of global forest area. They are also the most fire-prone northern ecosystem. Interior Alaska's boreal zone is dominated by black spruce: small, slow-growing trees that form dense stands. Their branches reach all the way down into the duff, providing a ladder for fire. As the dominant conifer in Alaska over the past 7,000 years, black spruce have adapted to the flames; their cones are clustered at the very top of the tree and open after a fire to shed seeds, which help to reestablish the ecosystem.

For decades fire managers in Alaska have monitored ignitions in remote areas and generally allowed them to burn, renewing the fire-dependent ecosystems; much of Alaska, after all, has few settlements or infrastructure to protect. This cost-effective approach has helped Alaska largely avoid the problem, common in the lower 48 states, of forests that are overgrown or have too much



Conditions Conspire to Magnify Fire

Climate change is amplifying wildfire in Alaska. Higher temperatures, particularly at night, are drying vegetation and the forest floor, enhancing flammability. Warmer weather is also shortening the weeks of snow cover, allowing dry conditions to persist for more of the year. Together these factors are lengthening the fire season, increasing acres burned. Similar patterns are occurring globally across the high north.



Sources: *Alaska's Changing Wildfire Environment*, by Z. Grabinski and H. R. McFarland, Alaska Fire Science Consortium, International Arctic Research Center, University of Alaska Fairbanks, 2020; Rick Thoman, based on data from NOAA and National Weather Service (*temperatures*); Brian Brettschneider, based on data from National Snow and Ice Data Center (*snow season*); Zav Grabinski, based on data from Alaska Interagency Coordination Center (*fire season*); Rick Thoman, based on data from Alaska Interagency Coordination Center (*acres burned*)

deadwood. The approach also means that in Alaska, researchers can see how climate is changing wildfire, without strong effects of human intervention.

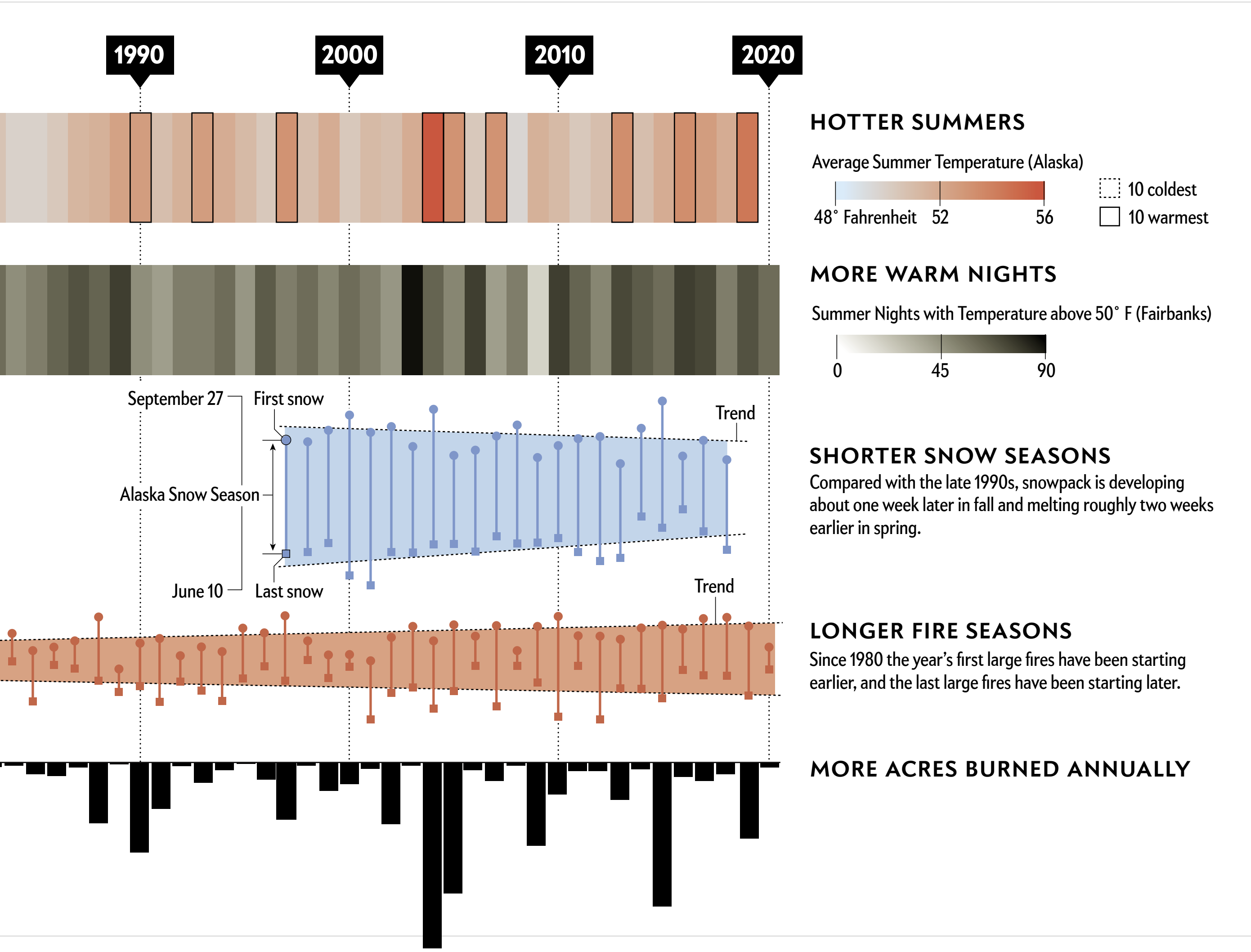
Until recently, fires would typically kill trees but would not penetrate too deeply into the duff, because moisture in the lower layers prevented deeper burning. Severe, deep burns have always happened on occasion during especially hot and dry conditions. In their aftermath, a mosaic of meadows, shrublands and hardwood forests (birch, poplar and aspen) typically emerges, replacing the spruce. Now these extreme events are increasing. In recent years forest fires in Alaska have broken records, burning more acreage, more intensely and for longer. Seasons in which a million or more acres burn are twice as frequent as 30 years ago.

The Arctic-boreal region as a whole is heating up 1.5 to four times faster than temperate zones. Alaska has warmed by four degrees F in the past 50 years, and evidence published in 2021 by David Swanson of the National Park Service Alaska Region suggests that warming has accelerated even more since 2014. This “Arctic amplification” is driven for the most part by disappearing sea and land ice, which leave larger areas of darker ocean and ground cover that absorb much more sunlight than ice or snow.

Winters are warming faster than summers, but the cumulative effect means snowpack is now developing a week later and melting two weeks earlier than in the 1990s, drying out duff for more of the year. Fire season is at least a month longer than it was 30 years ago, putting pressure on agencies to lengthen contracts for firefighters and aircraft. In 2016 Alaska set a record for fire-season length: smokejumpers, who parachute into remote locations, logged the earliest fire jump in their then 57-year history, near Palmer on April 17. And the Alaska Division of Forestry was still fighting flames near Anchorage in early October—in winds so cold they froze the water slopping from helicopter buckets overhead.

Extremely hot days, which are strongly linked to fire growth, are increasing as well. In 2019, the year of the Swan Lake and McKinley Fires, Anchorage set 32 new record highs and experienced 90 degrees F for the first time. According to the latest climate models, the annual number of days above 77 degrees F—a key threshold for

Graphic by Jen Christiansen



drying out burnable vegetation—is expected to double by midcentury Alaska's interior.

More high-latitude fire is happening worldwide. Within the Arctic Circle, 2020 was the record year for wildfires seen by satellite, and 2019 ranks second. In Siberia, estimates indicate that more than 18,000 fires burned 35 million acres in 2020—shocking numbers. Temperature anomalies nearby were remarkable. On June 20 the town of Verkhoyansk, at the same latitude as northern Alaska, hit a record: over 100 degrees F. In the region, precipitation was very low, and snow melt was the earliest since measurements began in 1967. Fire seasons in Russia's Sakha Republic are now two weeks longer than they were a decade ago, and early reports indicate Siberia's 2021 season through July was more extensive than the same period in 2020. In May, Iceland issued the country's first wildfire danger alert. The factors feeding these fires are the same as those in Alaska.

PERMAFROST AND LIGHTNING

BLACK SPRUCE BURN SPECTACULARLY, but most of the biomass that goes up in smoke is the duff itself. The forest floor can hold 40 to 100 tons of fuel per acre. The trees themselves add about 30 tons per acre, and even so flames often consume mostly needles and branches, leaving the denser tree trunks standing.

The duff, with its compact but airy layering, is a superb insulator of frozen ground underneath. Permafrost in these regions is widespread and tens of thousands of years old. Alaska is expected to lose 25 percent of its permafrost area by the end of the century just from warming. Fire can accelerate this process. When it leaves less than five inches of insulating duff, the permafrost underneath can thaw and degrade substantially. In Alaska's midlatitudes, fires may trigger enough thaw that the permafrost will never return, barring another Ice Age.

An extreme example of fire-induced thawing was the 2007 Anaktuvuk River Fire (ARF), which burned 250,000 acres of tundra in Alaska's northernmost region, the North Slope, at 70 degrees latitude. Fires beyond the Arctic Circle (67 degrees latitude) are rare; researchers had no record of a blaze this severe so far north. Lightning ignited the ARF in July. Although it appeared to be

BLACK SPRUCE conifers dominate Alaska's forests, but if they burn deeply, hardwoods such as birch, aspen and poplar may move in, changing habitat and ecosystems.

out by August, it smoldered silently in the duff under the treeless surface and then roared back to life during a warm September. The flames sent thick, billowing smoke over a wide area, choking residents of distant villages. Indigenous hunters said the smoke was disrupting the fall caribou migrations. Extremely dry autumn weather allowed the ARF to burn so deeply into drought-stricken duff that it continued to smolder into October, when lakes were frozen and snow again covered the region. Ultimately more than 400 square miles of continuous permafrost terrain was scarred.

The fire was so extraordinary that one of us (Jandt) initiated a study on behalf of the Bureau of Land Management's Alaska Fire Service into effects on vegetation and the active layer. In early July 2008, the start of the ensuing Arctic summer, the team arrived by helicopter to the ARF. Usually the North Slope at this time of year is cold, windy and drizzly. Instead the helicopter landed on a sea of charred ground under a clear blue sky. The temperature was a staggering 80 degrees F—way too warm for a heavy flight suit and insulated boots. It was so hot and dry that the usual hordes of mosquitoes were gone, replaced by swarms of blackflies.

The survey team saw cumulus clouds building from the warm, rising air masses, which can be fuel for a thunderstorm. Alaskans across interior parts of the state are accustomed to seeing summer heat spawn strong thunderstorms, especially during June and July, when the sun is up for almost 24 hours a day. Fires started by lightning are responsible for 90 percent of the acreage burned in Alaska and Canada's tundra and boreal forests. But lightning on the North Slope had been rare. An Inupiat elder and lifetime resident of Utqiagvik (formerly known as Barrow) said that she had never seen a thunderstorm prior to 1992.

Climate change is increasing lightning activity across the U.S., with the biggest changes at the highest latitudes. A 2014 study by David Romps of the University of California, Berkeley, predicted that each 1.8 degrees F (1 degree C) of warming brings 12 percent more lightning in the contiguous U.S. states. A 2019 analysis by Peter Bieniek of the University of Alaska Fairbanks revealed a 17 percent increase in lightning Alaska-wide over the past 30 years; in some regions, that number is as high as 600 percent. Models by Sander Veraverbeke, a professor of remote sensing at the Vrije Universiteit Amsterdam, predict that by 2050 Alaska will experience 59 percent more lightning, resulting in 78 percent more lightning-ignited wildfires, increasing burned area by 50 percent. A 2021 study found that lightning in the Arctic itself tripled from 2010 to 2020.

Arctic Alaska has experienced the most dramatic warming of any place in the state and, with it, the largest surge in lightning. Mean annual temperatures in Utqiagvik increased 11.4 degrees F from 1976 to 2018, and autumn temperatures have risen 18 degrees F.

LAND OF CHANGE

THE METAMORPHOSIS THE SURVEY TEAM noted during data gathering from 2008 through 2018 on the North Slope's ARF area parallels changes occurring after severe fires spread across Alaska and across the north. Each time the team was in the burn region it recorded plant cover and pushed metal probes down into the ground along numerous transects to measure the active layer. The thawed soil depth became deeper

WorldFoto *Alamy Stock Photo*

every year, from four inches greater than the same measurements made outside the burn area one year after the fire to 7.5 inches deeper after four years. Ten years later the active layer showed signs of recovery, possibly stopping the increasing depth of thaw.

Still, these measurements do not convey the magnitude of the surface alterations that took place on the ARF. The entire skin of the earth slid and cracked as the permafrost underneath thawed and the water drained away. Large parcels started to sink, or subside, because the volume of permafrost was disintegrating. From a helicopter, vast portions of the treeless region looked like a checkerboard of earthy squares; the dark, crevasselike channels that outline each of them were deepening significantly. Craters up to 200 feet wide opened where thawing destabilized slopes—a phenomenon called thermokarst mass wasting. Underground ice wedges that had not seen the sun for 60,000 years emerged, smelling like dead dinosaurs.

To chart the changing land, remote-sensing and permafrost experts Ben Jones and Carson Baughman of the U.S. Geological Survey joined the team excursions in 2017. Jones used airborne radar to confirm that surface subsidence was widespread, from four to 40 inches deep. Surface roughness, a measure of subsidence, over much of the eastern half of the burn area increased threefold, giving the landscape deeper channels, taller hummocks and more surface area.

Jones and Baughman left probes in burned and unburned areas that continued to record temperature. Measurements showed that the soil at six inches depth in the burned area averaged 2.7 degrees F warmer on an annual basis, and summer maximum temperatures were 11 degrees F warmer than in the unburned area. Obviously this warming jeopardizes permafrost, but it also influences the plants that will dominate the region. Ten years after the ARF fire, tall shrubs, grasses and other vascular plants, some of which had been rare beforehand, had increased tremendously. In warmer soils, fast-growing grasses and willow shrubs can outcompete the slower-growing mosses, lichens and dwarf shrubs that were prevalent before the fire. These newcomers add more dry litter to the fuel bed every year than the slow-growing mosses do. That may explain why in 2017, a decade after the ARF, there were two new fire scars roughly 100 acres apiece inside the 2007 burn expanse. Repeat fire in just 10 years was unusual inside a burn area where the likely time between subsequent fires has been estimated at several hundred years.

90% of acreage burned is from lightning fires

Lightning will increase **59%** by 2050

SINK OR SOURCE?

RESEARCHERS ARE WORKING HARD to understand the consequences of changing fire in the high north. The immediate impacts such as greenhouse gas emissions, poor air quality and infrastructure damage are obvious. Secondary impacts that can arise are challenging to predict. Some are expected, such as soil warming in summer as a result of the charred black surface, undulating landscapes and reestablishment of vegetation as burned plants resprout or reseed. Seasonally thawed soil can deepen; permafrost, if present, can subside. Low-lying areas can become temporarily wetter as ice thaws, helping grasses, shrubs and deciduous trees thrive.

Over time, however, more shrubs across tundra can make the ground even warmer. For one thing, they hold more snow, which insulates the ground from colder air. Burned slopes and ridges can become drier as thaw deepens, allowing even more subsurface drainage; new sensing technology has revealed "taliks"—pockets of unfrozen soil—deep under burned areas, which establish channels of thaw in the permafrost. In boreal forests, changes in habitat and the tree canopy alter patterns of animal movement. And microbes in warmer soils digest more of the ancient carbon in the duff and thawed permafrost, turning it into greenhouse gases, including methane.

More burning across boreal and tundra regions, along with cascading ecosystem changes, has global implications that only large computer models can estimate. The models predict that boreal burning may double or even quadruple by the end of this century, releasing massive quantities of carbon from the ubiquitous duff. That shift could transform the region from a carbon sink to a carbon source, which would amplify climate change worldwide.

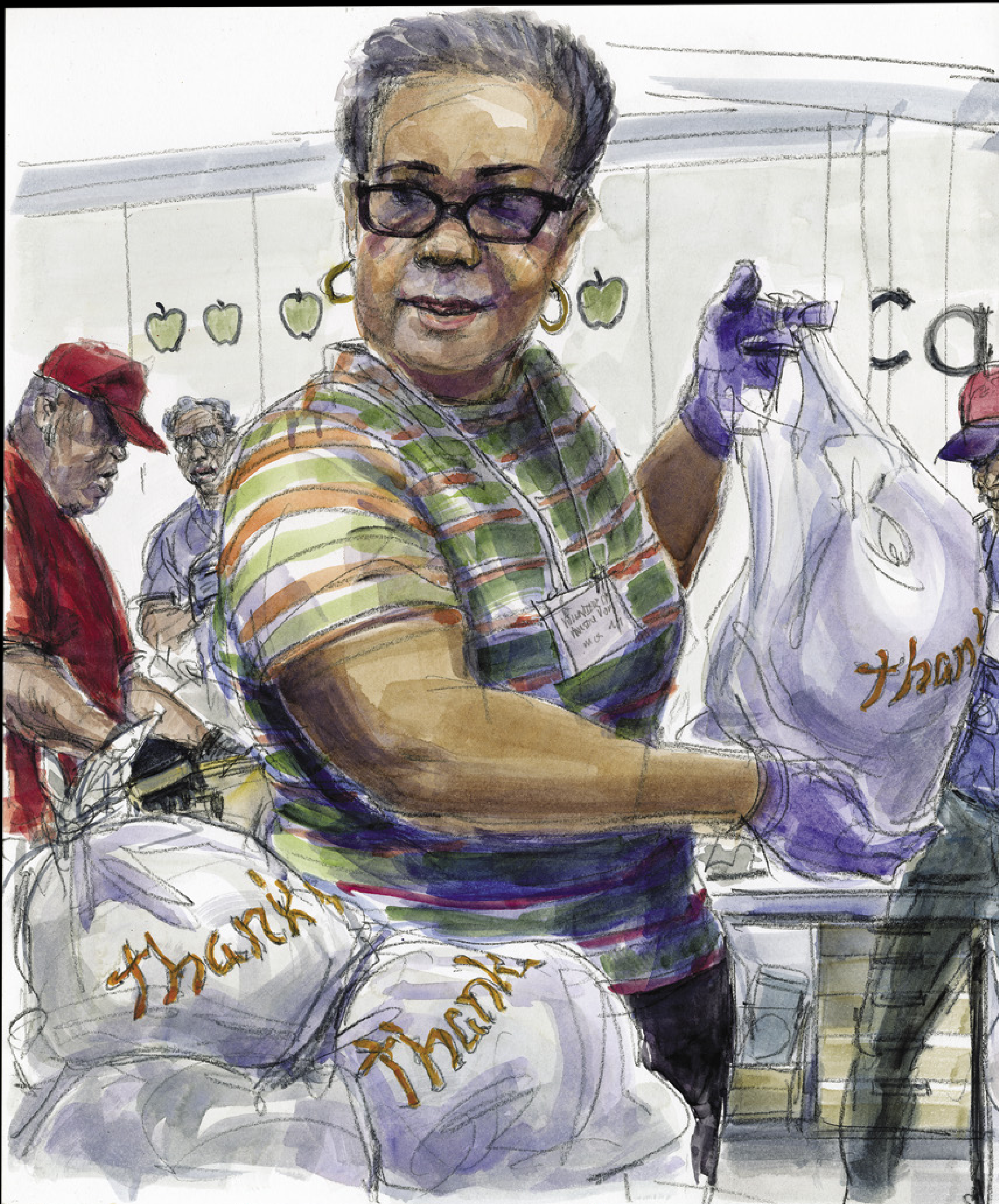
It may not be all bad news. Some studies indicate that a shift in forest composition from conifers such as spruce to less flammable deciduous trees such as birch and aspen, as well as a slight increase in rainfall attributed to less sea ice, may offset some of the predicted increase in area burned. If deciduous forests replace conifer forests after fire, they could reflect more sunlight, at least in winter when their leaves are gone and light reflects off the underlying snow, moderating the climate-warming feedback. Warmer tundra soils are already producing more shrubs and ultimately could support trees, which would sequester some of the carbon lost from soils and permafrost in their wood. But the devil is in the details. We need better estimates on each of these factors to predict how feedbacks will unfold.

While scientists work on those tasks, Alaska residents and fire agencies are strategizing about how to protect people, private land, infrastructure and natural resources in an intensifying fire environment. They are improving firefighting preparedness by thinning forest or removing burnable brush and vegetation around towns and cabins. And they are harnessing new technology—such as satellite imagery—for earlier fire detection and for accurate mapping and monitoring. More fire in the high north may alter the land and the climate, but Alaskans are trying to do as much as they can to prevent disastrous loss of life and property.

FROM OUR ARCHIVES

The Permafrost Prediction. Ted Shuur; December 2016.

scientificamerican.com/magazine/sa



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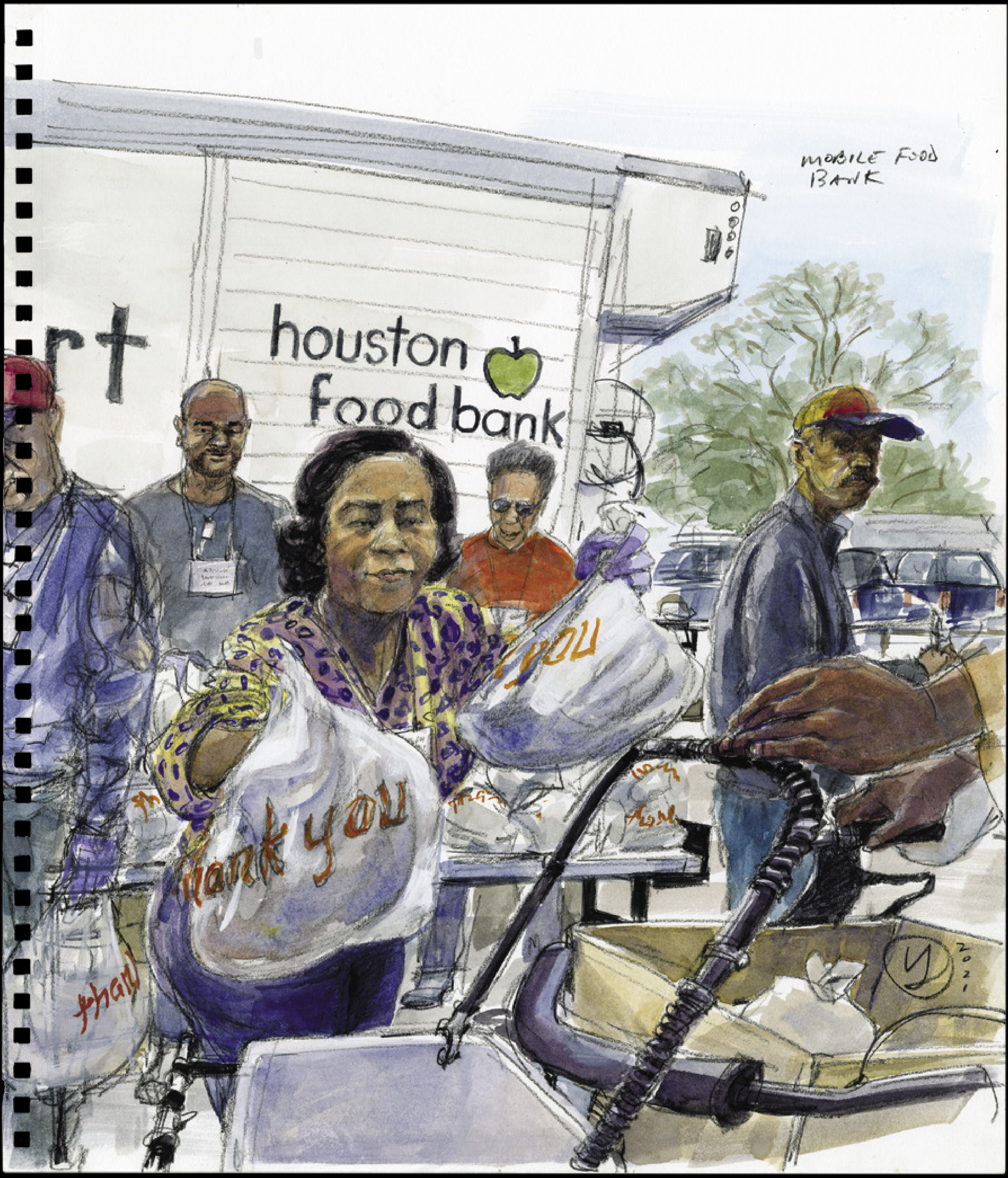

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Underserved Black communities are often depicted as dysfunctional. Their resiliency has long been overlooked

By Nancy Averett | Illustrations by Victor Juhasz

Nancy Averett writes about the environment and social science from Cincinnati, Ohio. Her work has appeared in *Audubon, Sierra, Discover,* and elsewhere.

GOOD EVENING," JACQUELINE MATTIS SAYS, SETTING A GLASS OF WATER down on a podium in the downtown branch of the Ann Arbor District Library in Michigan. The audience, mostly white and middle-aged, murmurs, "Good evening."

"Oh, no, no, no, no," Mattis says in a silky voice, holding up her hands in mock surprise. "I study religion. I study religion in the Black context, so let's start this again: good evening!"

"Good evening!" the crowd exclaims in return.

Mattis nods, and when a man adds, "Amen!" her smile widens. "Better response," she says, pointing at him. "Better response!"

It is January 2020, and Mattis, a professor of psychology and dean of faculty at the School of Arts and Sciences at Rutgers in Newark, N.J., is discussing her latest research subject: the transformative power of love and altruism among urban-residing Black people in the U.S. She shares a story about an interview she did with a young woman—referred to by the pseudonym "Saniyka"—who showed up at a homeless encampment when she was 15, along with her four younger siblings. The adults there quickly became surrogate parents, sharing their tents, washing the children's clothes and providing food. They were persistent about education and an alternative vision of the future. By the time Saniyka was a high school senior, she had the highest grades in her class. Her tent-city parents saved money to fund her college application fees.

The audience is rapt during the story, as Mattis figured they would be. Although many appear surprised to hear that people with so little would give so much, she is not. Mattis grew up in majority-Black neighborhoods—first in Kingston, Jamaica, then in the Bronx—where people lacked access to the rights, resources and opportunities that were enjoyed by white residents nearby. Mattis had caring, hardworking neighbors who looked out for one another. Yet as a young adult, she noticed that the media often portrayed such places as rife with violence and dysfunctional families and populated by weak, despairing people. In college she struggled when her professors described depravity and chaos in poor neighborhoods but never mentioned the grandmothers who used what little food they had to cook a meal for someone down the street who had even less. "Growing up that way and then hearing the [media and academic] representation of those spaces," she says, "I couldn't make sense of it. What I was reading didn't match my lived experience."

That dissonance led Mattis to pursue positive psychology research, which focuses on individuals' and communities' strengths rather than their deficits. Mattis and other researchers are examining how people in poorer communities subject to discrimination can achieve high levels of social capital, which is the ability to solve problems and thrive by forming mutually trusting, engaged relationships and networks. These particular social ties often bring about desired outcomes that would not be achieved in isolation.

Some researchers, however, believe social capital is the domain of the middle class or wealthy; that distressed or low-income communities cannot manufacture it themselves and therefore rely on interventions to build social capital. In fact, Mattis and other Black researchers have found that even in the most resource-poor neighborhoods, high levels of social capital not only exist but are used as a means to buffer the community against systematic oppression. In a world racked by a pandemic and climate disasters, this form of social consciousness, they say, should be celebrated and deeply studied.

RESILIENCE FROM SOCIAL CAPITAL

THE ROOTS of social capital can be found in the musings of 18th- and 19th-century intellectuals such as Alexis de Tocqueville, who on a visit to the U.S. in 1830 discovered that Americans loved to join associations and that such groups had positive effects on their members. "Feelings and ideas are renewed," he wrote, "the heart enlarged, and the understanding developed only by the reciprocal action of men one upon another." The term first turned up in the social science literature in 1916, when L. J. Hanifan, a progressive serving as West Virginia's state supervisor of rural schools, used it to argue for community involvement in schools. "The individual is helpless socially, if left entirely to himself," he wrote. "If he may come into contact with his neighbor ... there will be an accumulation of social capital, which may immediately satisfy his social needs and which may bear a social potentiality sufficient to the substantial improvement of living conditions in the whole community."

"Social capital" has been used among scholars of economics, politics, anthropology and psychology. It caught the greater public's eye when political science professor Robert D. Putnam of Harvard University published his best-selling 2000 book, *Bowling Alone: The Collapse and Revival of American Community.* In it, Putnam laments the decline of mainstream America's social clubs such as softball leagues, parent-teacher associations and Rotary Clubs, saying we have become so focused on individualism that we even bowl alone rather than in leagues. Putnam attributes this decline to such forces as suburbanization, increased television watching and generational shifts—people who grew up during the stress of the Great Depression and World War II, he says, felt the pull of community in a way that their children and grandchildren did not. He worries that this movement away from social and civic engagement has eroded democracy.

Other scholars elaborated on Putnam's hypotheses about increasing isolation. Harvard sociologist Theda Skocpol has argued that it is driven in part by wealthy Americans who may support professional nonprofits such as the Sierra Club or AARP but are less likely to participate in local grassroots groups. Matthew Crenson and Benjamin Ginsberg, political scientists at Johns Hopkins University, blame it on a range of factors that made it less likely citizens would band together to push the government to listen. For instance, a rise in litigation shifted the action of forcing legislators to change or enact laws from citizen organizing to advocacy groups working through the courts. And before the switch to an all-volunteer professional army, citizen soldiers who were drafted alongside their neighbors and friends made demands such as the expansion of voting rights to 18-year-olds.

Others fault social media for giving a false sense of civic engagement. In 2018 Eitan Hersh, a political science professor at Tufts University, found that a third of surveyed Americans reported spending two hours or more on politics every day. Yet those two hours were nearly always focused on consuming political news, arguing about politics online and thinking about politics. This "political hobbyism," he says, threatens our democracy because it takes up the time of well-meaning citizens who might otherwise be pursuing real political power by attending local planning meetings or knocking on doors to engage neighbors.

Examples from other nations show that social capital often improves mental health. For instance, social epidemiologist Ichiro Kawachi of Harvard has found that older survivors of a Japanese earthquake who had to move to temporary housing and therefore lost their long-standing social connections suffered greater cognitive decline than those who were able to remain in their homes. Epidemiologist Helen L. Berry of the University of Sydney has found examples of how collective responses to natural disasters can increase social capital. For instance, after Oxford, England, was inundated with floods six times in 10 years, an alliance formed in 2007 to work on flood-readiness projects. Berry insists that government leaders must address structural problems that harm communities. At the same time, when residents got together to learn how to install concrete blockades during flood warnings, it gave them a sense of achievement. "Acting for the greater good is powerfully protective of mental health," Berry says.

Most social capital studies—as with most kinds of research—typically focus on white, middle-class people. Some researchers have even doubted that social capital can really take hold in marginalized communities because of pervasive poverty. For instance, in his 2015 book, *Our Kids: The American Dream in Crisis,* Putnam argues there must be an extremely low level of social capital among poor families in the U.S. because they often do not have two parents at home, are less likely to attend church, and find few opportunities to participate in youth sports, scouts and other activities. The examples he uses to make his argument—such as a boy who grew up in a New Orleans housing project who brags about beating up other kids—are the kind that frustrate Mattis.

She, along with other Black researchers and Black community leaders, argues that social capital can be found in poor and marginalized neighborhoods if one bothers to look. "There have always existed pockets of resilience and agency embedded within even the most marginalized urban spaces," wrote LeConté Dill, a professor at Michigan State University, in a 2011 paper. While earning her doctorate at the University of California, Berkeley, Dill became interested in the protective factors that create resilience. She spent a summer observing the East Oakland Youth Development Center (EOYDC), where teenagers can participate in hip-hop dance classes, seminars on the Black experience, a "pathway to college" program, and more. One of those teenagers was Lanikque Howard, who grew up in a single-parent household in one of the area's poorest neighborhoods. While Howard's mother was working double shifts, Regina Jackson, who is president and CEO of the center, would drive Howard to the only post office open late so she could mail off yet another batch of scholarship applications.

The first in her family to get a college degree, Howard recently earned her doctorate in social work, and this year she was chosen by the Biden administration to join the Department of Health and Human Services' Administration for Children and Families. By supporting the development of individual resilience, Jackson has created a community of thriving young adults who then reach back to offer advice and encouragement—personal tours of their college campuses; job leads—to the current teens who are coming up through EOYDC's programming. Dill calls this "bridging" social capital because it can improve the teens' social mobility. She also identified a type of interpersonal social capital that people draw on to "get by" and cope with daily problems—what Jackson describes in lay terms as encouraging a sense of "personal sustainability" in the teens "so they believe that they deserve to be successful." Jackson's charges often return to the Oakland area to work so they can help their old neighborhoods, thus building even more community resilience.

Dill and Mattis, as well as other researchers in psychology, social work, epidemiology, public health, and other fields, are building up a body of published evidence showing that a current of collectivism runs through majority-Black enclaves that can help make people more resilient than they might be otherwise. Their work has sometimes met with skepticism. Mattis, for example, says peer-reviewers have accused her of making up the personal stories of altruism that she has gathered from people she has interviewed (she offered to let them listen to recordings), and some scholars have told her it is irresponsible to study goodness in poor urban spaces because it might give the impression that there are not big problems in places affected by structural racism and inequality.

Mattis counters that it is misleading to ignore altruism and how it helps people cultivate social capital. During the COVID pandemic, scholars have noted how an extreme focus on individualism in American culture has led to tragic results. But that is too sweeping an assessment. “In the Black community, we have to take care of ourselves,” says Traci Blackmon, a Missouri pastor. In the early days of the pandemic, her church collected 30,000 masks and many gallons of hand sanitizer to give to Black frontline workers such as bus drivers, grocery store clerks and cafeteria workers. “Black people, in my opinion, and all nonwhite people have this sense of community embedded in our DNA out of necessity that says we have to share what we have in order for everyone to be okay.” These altruistic behaviors, Mattis says, “reinforce the fact that you’re fully human in a world that doesn’t tell you that you’re fully human. That gives you a different picture of yourself.”

Because so many things in society—democracy, saving lives during a pandemic, action on climate change—work better when we have strong social capital, it makes sense to study how it is created and sustained. Understanding how it manifests in majority-Black communities, Mattis says, could inform efforts to strengthen society overall.

SPIRITUALITY IS WHEN YOU’VE BEEN TO HELL

COLLECTIVISM in Black communities—what some social scientists have called the “Black helping tradition”—can be traced back to at least the late 1700s, when two formerly enslaved men, Richard Allen and Absalom Jones, founded the Free African Society, a mutual-aid society that eventually led to the first U.S. Black religious denomination: African Methodist Episcopal. The society gave newly freed people goods and services they could not get elsewhere: money, jobs, education, clothes, health care and religious instruction.

Churches were some of the few places where Black Americans could gather safely for any kind of public discourse. Martin Luther King, Jr., famously used the church in the fight for civil rights, and the Black Panthers held free breakfasts for Black children in church basements. “For Blacks especially, churches provide an opportunity to be civically engaged with a protective covering of unity and support,” wrote Keon Gilbert, a behavioral sciences professor at St. Louis University, and Lorraine Dean, an epidemiologist at the Johns Hopkins Bloomberg School of Public Health, in their research looking at health and political advocacy.

Mattis began studying religion and spirituality and their connection to the psychological welfare of the Black community by using surveys and in-depth interviews when she was in graduate school at the University of Michigan. At the time, she was struggling with her mother’s exhortation—“You have a responsibility to tell our story”—and the often negative portrayals her professors shared about people in majority-Black neighborhoods. She knew from personal experience that religion and spirituality had helped instill resiliency in her neighbors, allowing them to remain hopeful despite their unjust circumstances and to create a sense of responsibility toward one another. "It was the thing that helped everyone I knew live lives of dignity," she says.

Her work has shown that many Black Americans take solace in a kind of racial righteousness—a conviction that racism is a sin in the eyes of God and that Jesus, who championed the oppressed, is on their side—and this belief is a source of optimism. She has also found a distinction between religion and spirituality. As one woman she interviewed put it: "Religion is what you do when you're afraid of going to hell, and spirituality is what you do when you've already been there." That sentiment, Mattis says, "captures what happens when life really pushes you to your limits. You develop a personal sense of what's sacred, what's important."

She points out that it is a relationship that does not always sit well with mainstream, predominantly white psychology. Sigmund Freud notably described religions as escapist, illogical and pathological responses to adversity and existential angst. The push for psychology to become evidence-based has led many scholars to shy away from looking at religion and spirituality as relevant to mental health. Further complicating the matter is the fact that studies also show that psychologists and therapists overwhelmingly identify as atheist or agnostic. "As a young student, I learned early on that social work was a secular field and that people who have a strong faith background almost have to be prepared to tuck it in their pocket," says Ratonia Runnels, an assistant professor of social work at Texas Woman's University, who nonetheless studies how religion might be integrated into social work.

In 2011 Runnels published a study looking at how Black survivors of Hurricane Katrina used spirituality and religion to cope. She and her co-authors analyzed interviews with 52 Black survivors and 98 service providers described as government officials, therapists, social workers, pastors, case managers and volunteers. Their work showed that the secular providers were surprised by the survivors' deep faith. They also found that some pastors were treated with hostility. One pastor said he was rebuffed when he tried to counsel survivors at a shelter; officials told him they had medical staff to take care of physical needs and mental health workers to take care of mental health needs. The man said he pointed out that there was another component, people's spiritual needs, but was turned away.

As a Black woman who is religious herself, Runnels understands that the spirituality found in Black churches—a belief that a higher power is looking out for the congregants—inspires people to be the embodiment of that power by taking care of one another. Black liberationist theology, which emerged during the Civil Rights Movement, emphasizes that social action on behalf of the Black community is part of the spiritual responsibility of the faithful. And because worshippers share a similar identity and values—two things that Putnam says are key—social capital flows in such spaces.

Charles X. White of Houston, a school safety consultant by day and a community worker by night, sometimes uses churches to hold his long-running series of community breakfasts focused on civic engagement. The attendees, mostly older women, recite a pledge in which they promise to work to better their neighborhoods. Between bites of biscuits and gravy, they listen as White, who speaks in a deep baritone, introduces speakers such as politicians looking for help getting out the vote, city health and human services workers explaining how to file pollution complaints, and county police officers demonstrating evacuation techniques for extreme weather events. The last is a crucial topic to his audience. After suffering through Hurricane Harvey in 2017, people want to be more prepared for the next storm, but they are not confident that they can be. Some worry that if they are too pushy—say, insisting that public works employees clear debris from drainage ditches near their homes to prevent flooding—city workers might retaliate by sending police to harass them. "There's a lot of fear," says White, who encourages his attendees to overcome anxieties and take action by giving them hard facts such as a copy of the city code on drainage-ditch maintenance. "When people are uncertain, they don't push," he says. "But most people get emboldened once they know they're right. They'll hold up this piece of paper and say, 'Hey, look, man, this is what the code says!'"

There is evidence that White's breakfasts are doing exactly what Kawachi and Berry say social capital does: bolstering people's psyches. Two months after Harvey hit, Garett Sansom, an associate professor at Texas A&M's School of Public Health, came to a breakfast meeting to see whether he could gauge how a group of Houston's low-income Black residents were faring after the storm. Sansom administered the 12-item Short-Form Health Survey, a standard public health tool that measures physical and mental health, to the 153 people in the audience. The results surprised him. The survey almost always shows a correlation between physical and mental health scores—if one is low, so is the other. "That's been shown across lots of different communities, including the African-American community," he says. "But what we found was that in this group, even though they had greatly reduced physical health scores … they actually had higher mental health scores." In other words, despite living in neighborhoods that suffered some of the worst impacts of the storm, they were less depressed, traumatized and anxious than other people in the area.

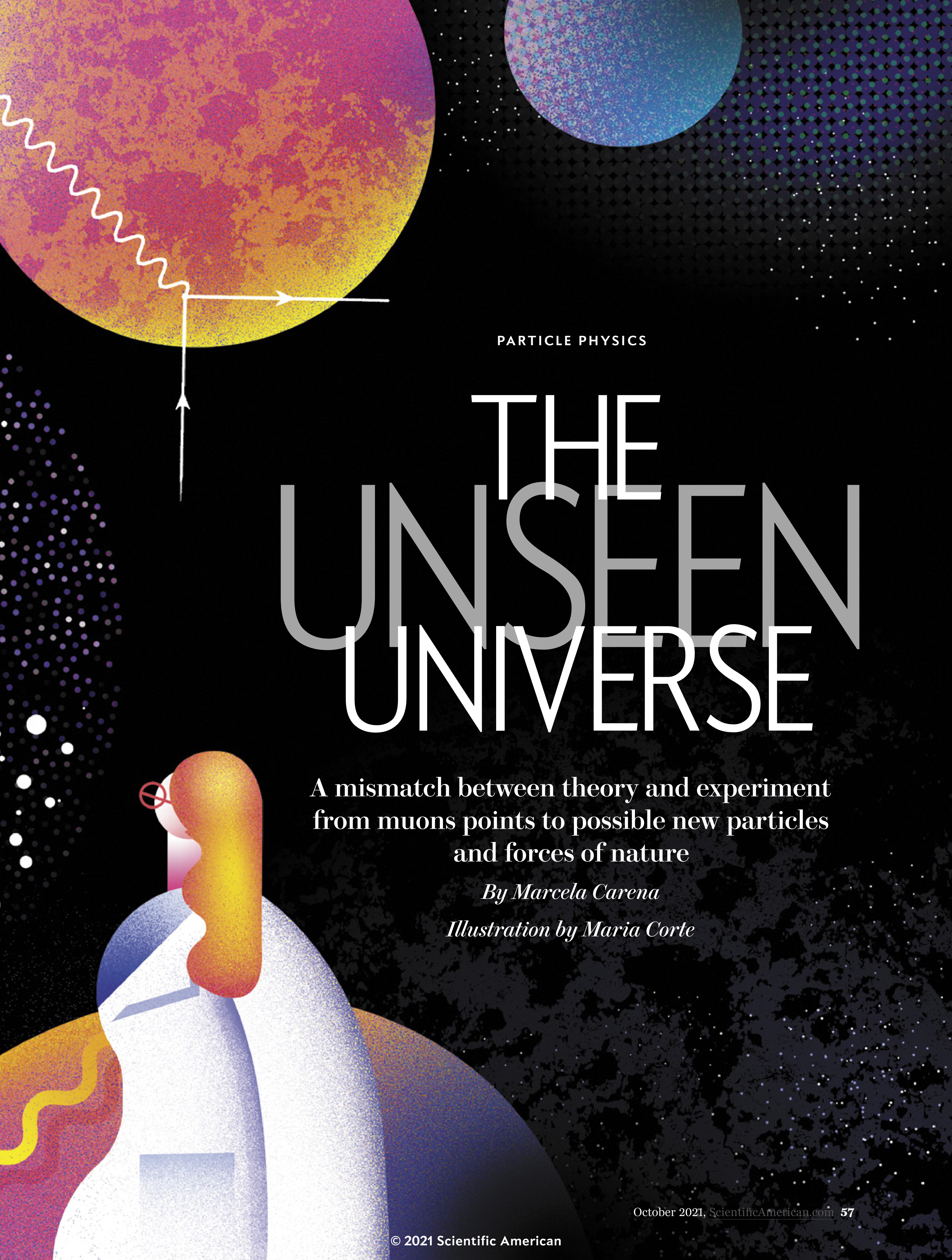
Mattis knows well the positive effects of social capital on mental health. Yet she cautions against using conventional definitions of success as proof of resilience. At the library in Ann Arbor, her story about Saniyka, the valedictorian, doesn't have an obvious fairy-tale ending. Saniyka still dreams of going to college but for a variety of reasons has not yet attended one. Nevertheless, the young woman is employed at a nonprofit that works with vulnerable people. Having been homeless herself (she now shares a one-bedroom apartment with four people she met in the tent city), Saniyka has thrived in this position, according to Mattis. Saniyka approaches people she meets on the street and engages them in conversation, hoping to learn their hidden talents and encourage them to contribute to her organization. She recognizes that every person has something valuable to offer—a perspective that Mattis shares.

If academics, policy makers and others in the mainstream fail to see the social capital in marginalized communities—the ways people cope and even thrive in very difficult circumstances—then society as a whole suffers, she says. "You see people who are much better resourced than [Saniyka], who sort of lapse into this mindset of hopelessness and selfishness in the face of adversity," Mattis explains. "And she, instead of looking inward and becoming isolated, takes all those experiences and decides to focus outward on changing the world so it doesn't have to look that way for others." ■

FROM OUR ARCHIVES

The Biggest Psychological Experiment. Lydia Denworth; July 2020.

scientificamerican.com/magazine/sa



PARTICLE PHYSICS

THE UNSEEN UNIVERSE

A mismatch between theory and experiment from muons points to possible new particles and forces of nature

By Marcela Carena

Illustration by Maria Corte

Marcela Carena is a particle physicist and head of the Theory Division at Fermi National Accelerator Laboratory in Batavia, Ill., and a professor of physics at the University of Chicago, where she is a member of the Enrico Fermi Institute and the Kavli Institute for Cosmological Physics.

AFTER LEAVING THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN) physics laboratory years ago, I crossed the Swiss-German border by high-speed train. Looking out the window of the carriage, I was enthralled by the scenes flashing by: a young couple embracing on an otherwise deserted platform, an old man standing by a rusty wagon with a missing wheel, two girls wading into a reedy pond. Each was just a few flickering frames, gone in the blink of an eye, but enough for my imagination to fill in a story.

I had just finished writing up some theoretical work on muon particles—heavier cousins to electrons—and it was out for the scrutiny of my particle physics colleagues during peer review. There was a symmetry between my thoughts as I looked out the train window that day and the research I had been working on. I had been analyzing the flickering effects of unseen "virtual" particles on muons, aiming to use the clues from these interactions to piece together a fuller picture of our quantum universe. As a young theorist just launching my career, I had heard about proposed experiments to measure the tiny wobbles of muons to gather such clues. I had just spent my last few months at CERN working on an idea that could relate these wobbling muons to the identity of the missing dark matter that dominates our universe and other mysteries. My mind fast-forwarding, I thought, "Great—now I just have to wait for the experiments to sort things out." Little did I suspect that I would end up waiting for a quarter of a century.

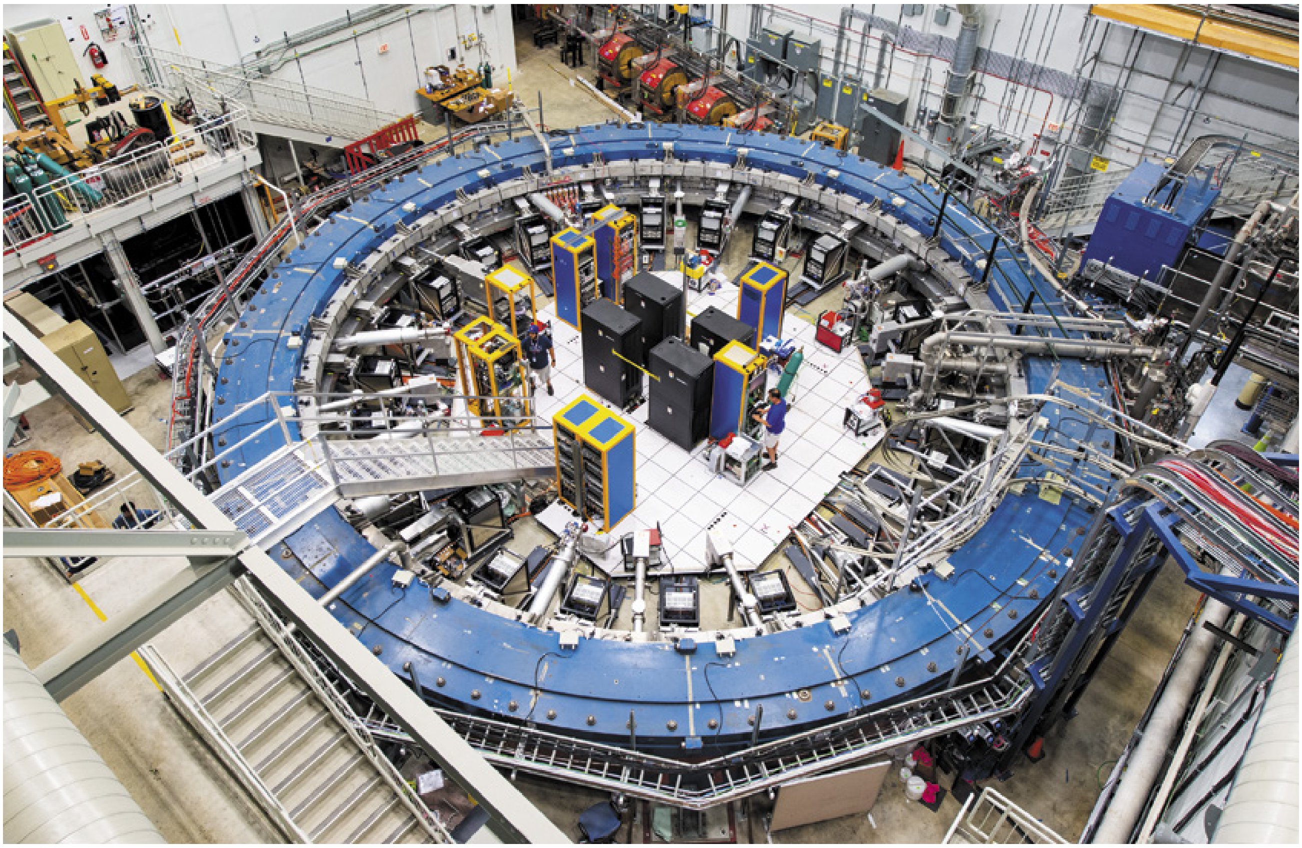
Finally, this past April, I tuned in to a Webcast from my home institution, Fermi National Accelerator Laboratory (Fermilab) near Chicago, where scientists were reporting findings from the Muon g-2 ("g minus two") experiment. Thousands of people around the world watched to see if the laws of physics would soon need to be rewritten. The Fermilab project was following up on a 2001 experiment that found tantalizing hints of the muon wobble effect I had been hoping for. That trial didn't produce enough data to be definitive. But now Muon g-2 cospokesperson Chris Polly was unveiling the long-awaited results from the experiment's first run. I watched with excitement as he showed a collection of new evidence that agreed with the earlier trial, both suggesting that muons are not acting as current theory prescribes. With the evidence from these two experiments, we are now very near the rigorous statistical threshold physicists require to claim a "discovery."

What is this wobble effect that has me and other scientists so intrigued? It has to do with the way a muon spins when it travels through a magnetic field. This variation in spin direction can be affected by virtual particles that appear and disappear in empty space according to the weird rules of quantum mechanics. If there are additional particles in the universe beyond the ones we know about, they, too, will show up as virtual particles and exert an influence on a muon's spin in our experiments. And this seems to be what we are seeing. The Fermilab experiment and its precursor measured a stronger wobble in muons' spins than what we expect based on just the known particles. If the current discrepancy holds up, this will be the biggest breakthrough in particle physics since the discovery of the Higgs boson—the most recent novel particle discovered. We might be observing the effects of particles that could help unveil the identity of dark matter or even reveal a new force of nature.

THE STANDARD MODEL

MY ROMANCE WITH PHYSICS began when I was a child, gazing in amazement at the *Via Lactea* (the Milky Way) in the deep dark sky of Argentina's Pampas where I grew up. The same wonder fills me now. It is my job as a particle physicist to investigate what the universe is made of, how it works and how it began.

Scientists believe there is a simple yet elegant mathematical structure, based on symmetries of nature, that describes the way microscopic elementary particles interact with one another through the electromagnetic, weak and strong forces; this is the miracle of particle physics that scientists prosaically call the Standard Model. The distant stars are made of the same three elementary matter particles as our bodies: the electron and the "up" and "down" quarks, the two latter of which form protons and neutrons. Starlight is the result of the electromagnetic force acting between the charged protons and electrons, liberating light energy at the hot surface of the star. The heat source of these stars, including our sun, is the strong force, which acts on the protons and neutrons to produce nuclear fusion. And the weak force, which operates on both the quarks and the elec-



Reidar Hahn *Fermi National Accelerator Laboratory*

SPINNING MUONS: Particles circle around this 50-foot-diameter ring in the Muon g-2 experiment.

trons, turns protons into neutrons and positively charged electrons and controls the rate of the first step in the fusion process. (The fourth force of nature, gravity, is not part of the Standard Model, although integrating it with the other forces is a major goal.)

Physicists assembled the Standard Model piece by piece over the course of decades. At particle accelerators around the world, we have been able to create and observe all of the particles that the mathematical structure requires. The last to be found, the Higgs boson, was discovered almost a decade ago at CERN's Large Hadron Collider (LHC). Yet we know the Standard Model is not complete. It does not explain, for example, the 85 percent of the matter in the universe—dark matter—that holds the cosmos together, making galaxies such as our Milky Way possible. The Standard Model falls short of answering why, at some early time in our universe's history, matter prevailed over antimatter, enabling our existence. And the Muon g-2 experiment at Fermilab may now be showing that the Standard Model, as splendid as it is, describes just a part of a richer subatomic world.

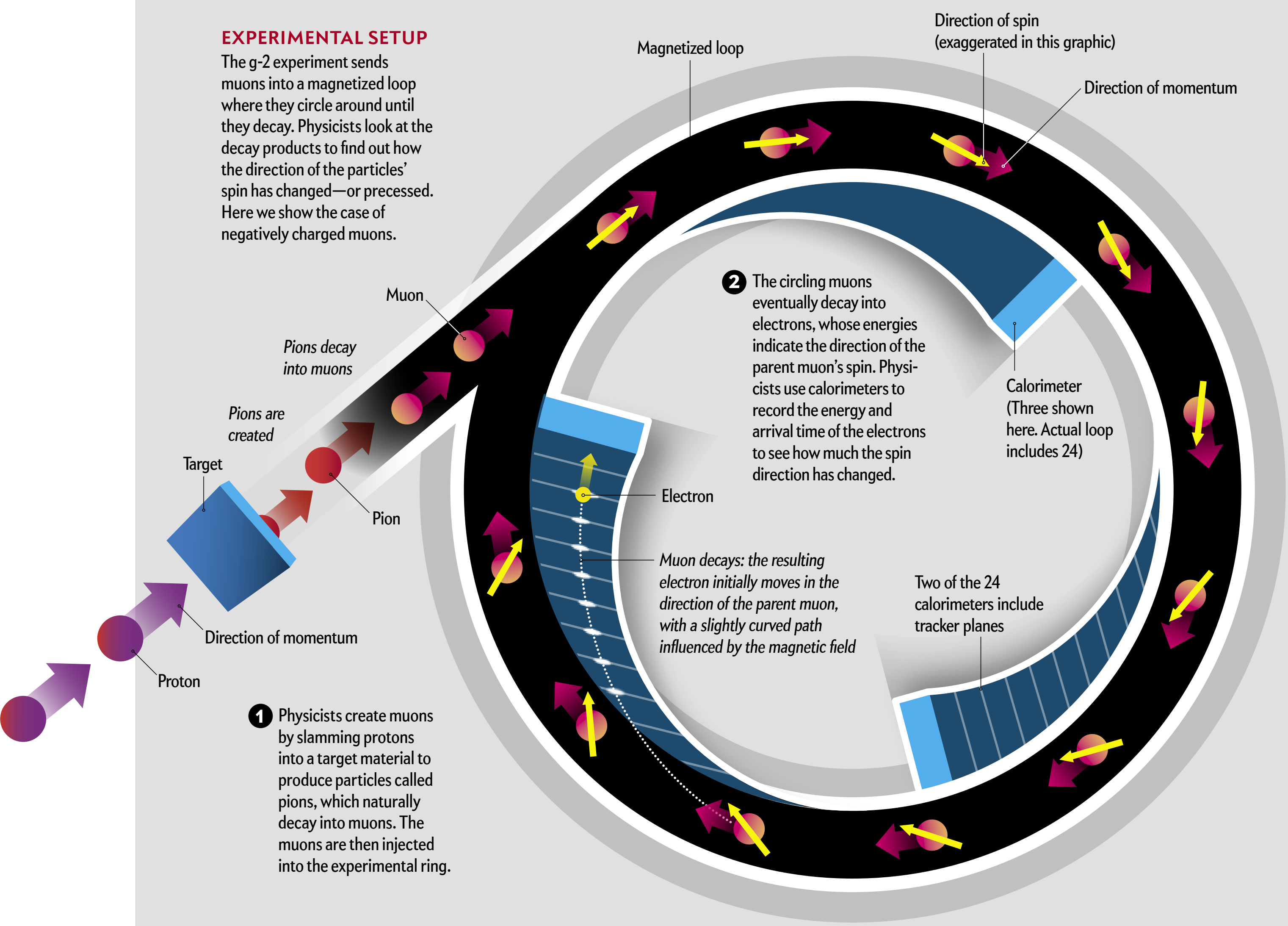
The subject of the experiment—muons—are produced in abundance by cosmic rays in Earth's atmosphere; more than 10,000 of them pass through our bodies every minute. These particles have the same physical properties as the familiar electron, but they are 200 times heavier. The extra mass makes them better probes for new phenomena in high-precision laboratories because any deviations from their expected behavior will be more noticeable. At Fermilab, a 50-foot-diameter ring of powerful magnets stores muons created under controlled conditions by smashing a beam of protons from a particle accelerator into a target of mostly nickel. This process produces pions, unstable composite particles that then decay into neutrinos and muons through weak force effects. At this point, the muons enter a ring filled with the vacuum of "empty" space.

Like electrons, muons have electric charge and a property we call spin, which makes them behave as little magnets. Because of the way they were created, when negatively charged muons enter the ring their spins point in the same direction as their motion, whereas for positively charged muons (used in the Fermilab experiment) the spins point in the opposite direction of their motion. An external magnetic field makes the electrically charged muons orbit around the ring at almost the speed of light. At the same time, this magnetic field causes the spin of the muons to precess smoothly like a gyroscope, as the particles travel around the ring, but with a small wobble.

The rate of precession depends on the strength of the muon's internal magnet and is proportional to a factor that we call g. The way the equations of the Standard Model are written, if the muon didn't wobble at all, the value of g would be 2. If that were the case, the muon's direction of motion and direction of spin would always be the same with respect to each other, and g-2 would be zero. In that case, scientists would measure no wobble of the muon. This situation is exactly what we would expect without considering the properties of the vacuum.

Wobbling Muons

Physicists studying muon particles recently found that they do not behave as expected. Muons are charged particles similar to electrons, but heavier, and when moving in circles within a magnetic field, their spin wobbles. Scientists predicted this, but they did not expect them to wobble as much as they do. The findings, from the Muon g-2 experiment at Fermi National Accelerator Laboratory (Fermilab) near Chicago, suggest something exciting may be afoot.



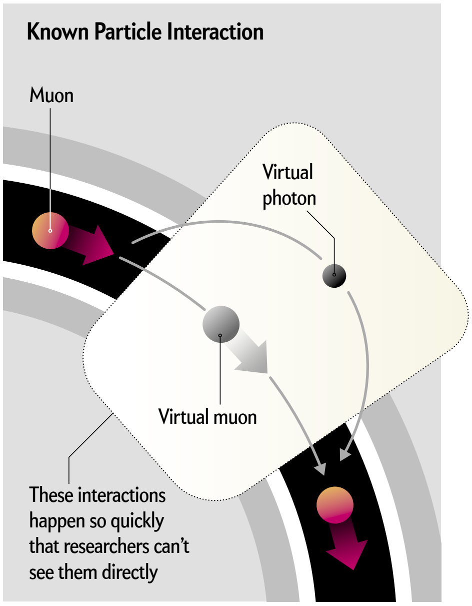
But quantum physics tells us that the nothingness of empty space is the most mysterious substance in the universe. This is because empty space contains virtual particles—short-lived objects whose physical effects are very real. All the Standard Model particles we know of can behave as virtual particles as a result of the uncertainty principle, an element of quantum theory that limits the precision with which we can perform measurements. As a result, it is possible that for a very short time the uncertainty in the energy of a particle can be so large that a particle can spring into existence from empty space. This mind-blowing feature of the quantum world plays a crucial role in particle physics experiments; indeed, the discovery of the Higgs boson was enabled by virtual particle effects at the LHC.

Virtual particles also interact with the muons in the Fermilab ring and change the value of g. You can imagine the virtual particles as ephemeral companions that a muon emits and immediately reabsorbs—they follow it around like a little cloud, changing its magnetic properties and thus its spin precession. Therefore, scientists always knew that g would not be exactly 2 and that there would be some wobble as muons spin around the

Illustration by Jen Christiansen

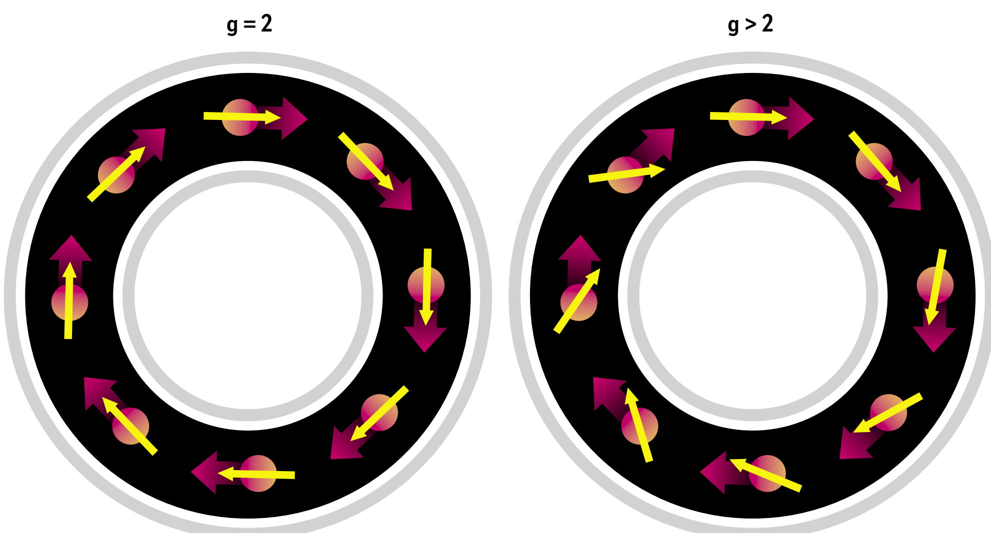
THE VACUUM FACTOR

If the muons were alone in the experiment, their spins would not wobble. But scientists know empty space is never really empty: "virtual" particles continuously appear and disappear from the fluctuating energy of the vacuum. Physicists can calculate how much of a wobble effect would arise from the known particles in the universe, but if undiscovered particles exist, they would add to the wobble. Such particles could include the "smuon" and "neutralino" predicted by supersymmetry.



THE RESULTS

Scientists at the Muon g-2 experiment measured significantly more wobbling than the Standard Model of physics predicts. If virtual particles were not present, the factor g-2 would equal zero. But with virtual particle interactions, g becomes greater than 2, and the spin direction diverges from the muon's direction of momentum. The findings suggest that novel particles may be contributing to g-2.



ring. But if the Standard Model is not the whole story, then other particles that we have not yet discovered may also be found in that cloud, changing the value of g in ways that the Standard Model cannot predict.

Muons themselves are unstable particles, but they live long enough inside the Muon g-2 experiment for physicists to measure their spin direction. Physicists do this by monitoring one of the decay particles they create: electrons, from decays of negatively charged muons, or positrons—the antiparticle version of electrons—from decays of positively charged muons. By determining the energy and arrival time of the electrons or positrons, scientists can deduce the spin direction of the parent muon. A team of about 200 physicists from 35 universities and labs in seven countries developed techniques for measuring the muon g-2 property with unprecedented accuracy.

A CONFIRMATION

THE FIRST EXPERIMENTS to measure the muon g-2 took place at CERN, and by the late 1970s they had produced results that, within their impressive but limited precision, agreed with standard the-

BY BOAT AND BIG RIG: Getting the Muon g-2 ring to Fermilab from Brookhaven required a barge and a specialized truck.

ory. In the late 1990s the E821 Muon g-2 experiment at Brookhaven National Laboratory started taking data, with a similar setup to that at CERN. It ran until 2001 and got impressive results showing an intriguing discrepancy from the Standard Model calculations. It collected only enough data to establish a three-sigma deviation from the Standard Model—well short of the five-sigma statistical significance physicists require for a "discovery."

A decade later Fermilab acquired the original Brookhaven muon ring, shipped the 50-ton apparatus from Long Island to Chicago via highways, rivers and an ocean, and started the next generation of the Muon g-2 experiment. Nearly a decade after *that,* Fermilab announced a measurement of muon wobble with an uncertainty of less than half a part in a million. This impressive accuracy, achieved with just the first 6 percent of the expected data from the experiment, is comparable to the result from the full run of the Brookhaven trial. Most important, the new Fermilab results are in striking agreement with the E821 values, confirming that the Brookhaven findings were not a fluke.

To confirm this year's results, we need not just more experimental data but also a better understanding of what exactly our theories predict. Over the past two decades we have been refining the Standard Model predictions. Most recently, more than 100 physicists working on the Muon g-2 Theory Initiative, started by Aida El-Khadra of the University of Illinois, have strived to improve the accuracy of the Standard Model's value for the muon g-2 factor. Advances in mathematical methods and com putational power have enabled the most accurate theoretical calculation of g yet, taking into account the effects from all virtual Standard Model particles that interact with muons through the electromagnetic, weak and strong forces. Just months before Fermilab revealed its latest experimental measurements, the theory initiative unveiled their new calculation. The number disagrees with the experimental result by 4.2 sigma, which means that the chances that the discrepancy is purely a statistical fluctuation are about one in 40,000.

Still, the latest theoretical calculation is not iron-clad. The contributions to the g-2 factor governed by effects from the strong force are extremely difficult to compute. The Muon g-2 Theory Initiative used input from two decades of judiciously measured data in related experiments with electrons to evaluate these effects. Another technique, though, is to try to calculate the size of the effects directly from theoretical principles. This calculation is way too complex to solve exactly, but physicists can make approximations using a mathematical trick that discretizes our world into a gridlike lattice of space and time. These techniques have yielded highly accurate results for other computations where strong forces play a dominant role.

Teams around the world are tackling the lattice calculations for the muon g-2 factor. So far only one team has claimed to have a result of comparable accuracy to those based on experimental data from electron collisions. This result happens to dilute the discrepancy between the experimental and Standard Model expectations—if it is correct, there may not be evidence of additional particles tugging on the muon after all. Yet this lat-

Reidar Hahn *Fermi National Accelerator Laboratory* tice result, if confirmed by other groups, would itself conflict with experimental electron data—the puzzle then would be our understanding of electron collisions. And it would be hard to find theoretical effects that would explain such a result because electron collisions have been so thoroughly studied.

A MESSAGE FROM THE VOID

IF THE MISMATCH between Fermilab's measurements and theory persists, we may be glimpsing an uncharted world of unfamiliar forces, novel symmetries of nature and new particles. In the research I published 25 years ago searching for clues about the muon's wobble, my collaborators and I considered a proposed property of nature called supersymmetry. This idea bridges two categories of particles—bosons, which can be packed together in large numbers, and fermions, which are antisocial and will share space only with particles of opposite spin. Supersymmetry postulates that each fermion matter particle of the Standard Model has a yet to be discovered boson particle superpartner, and each Standard Model boson particle also has an undiscovered fermion superpartner. Supersymmetry promises to unify the three Standard Model forces and offers natural explanations for dark matter and the victory of matter over antimatter. It may also explain the striking Muon g-2 results.

Just after the Fermilab collaboration announced its measurement, my colleagues Sebastian Baum, Nausheen Shah, Carlos Wagner and I posted a paper to a preprint server investigating this intriguing notion. Our calculations showed that virtual superparticles in the vacuum could make the muons wobble faster than the Standard Model predicts, just as the experiment saw. Even more exhilarating, one of those new particles—called a neutralino—is a candidate for dark matter. Supersymmetry can take numerous forms, many of them already ruled out by data from the LHC and other experiments—but plenty of versions are still viable theories of nature.

The paper my team submitted was just one of more than 100 that have appeared proposing possible explanations for the Muon g-2 result since it was announced. Most of these papers suggest new particles that fall into one of two camps: either "light and feeble" or "heavy and strong." The first category includes new particles that have masses comparable to or smaller than the muon and that interact with muons with a strength millions of times weaker than the electromagnetic force. The simplest theoretical models of this type involve new, lighter cousins of the Higgs boson or particles related to new forces of nature that act on muons. These new light particles and feeble forces could be hard to detect in terrestrial experiments other than Muon g-2, but they may have left clues in the cosmos. These light particles would have been produced in huge numbers after the big bang and might have had a measurable effect on cosmic expansion. The same idea—that light particles and feeble forces wrote a chapter missing from our current history of the universe—has also been proposed to explain discrepancies in observations of the expansion rate of space, the so-called Hubble constant crisis.

The second category of explanations for the muon results—heavy and strong—involves particles with masses about as heavy as the Higgs boson (roughly 125 times the mass of a proton) to up to 100 times heavier. These particles could interact with muons with a strength comparable to the electromagnetic and weak interactions. Such heavy particles might be cousins of the Higgs boson, or exotic matter particles, or they might be carriers of a new force of nature that works over a short range. Supersymmetry offers some models of this type, so my youthful speculations at CERN are still in the running. Another possibility is a new type of particle called a leptoquark—a strange kind of boson that shares properties with quarks as well as leptons such as the muon. Depending on how heavy the new particles are and the strength of their interactions with Standard Model particles, they might be detectable in upcoming runs of the LHC.

Some recent LHC data already point toward unusual behavior involving muons. Recently, for instance, LHCb (one of the experiments at the LHC) measured the decays of certain unstable composite particles similar to pions that produce either muons or electrons. If muons are just heavier cousins of the electron, as the Standard Model claims, then we can precisely predict what fraction of these decays should produce muons versus electrons. But LHCb data show a persistent three-sigma discrepancy from this prediction, perhaps indicating that muons are more different from electrons than the Standard Model allows. It is reasonable to wonder whether the results from LHCb and Muon g-2 are different, flickering frames of the same story.

ONE PUZZLE PIECE

THE MUON G-2 EXPERIMENT may be telling us something new, with implications far beyond the muons themselves. Theorists can engineer scenarios where new particles and forces explain both the muons' funny wobbling and solve other outstanding mysteries, such as the nature of dark matter or, even more daring, why matter dominates over antimatter. The Fermilab experiment has given us a first glimpse of what is going on, but I expect it will take many more experiments, both ongoing and yet to be conceived, before we can confidently finish the story. If supersymmetry is part of the answer, we have a fair chance of observing some of the superparticles at the LHC. We hope to see evidence of dark matter particles there or in deep underground labs seeking them. We can also look at the behavior of muons in different kinds of experiments, such as LHCb.

All of these experiments will keep running. Muon g-2 should eventually produce results with nearly 20 times more data. I suspect, however, that the final measured value of the g-2 factor will not significantly change. There is still a shadow of doubt on the theory side that will be clarified in the next few years, as lattice computations using the world's most powerful supercomputers achieve higher precision and as independent teams converge on a final verdict for the Standard Model prediction of the g-2 factor. If a big mismatch between the prediction and the measurement persists, it will shake the foundations of physics.

Muons have always been full of surprises. Their very existence prompted physicist I. I. Rabi to complain, "Who ordered that?" when they were first discovered in 1936. Nearly a century later they are still amazing us. Now it seems muons may be the messengers of a new order in the cosmos and, for me personally, a dream come true.

FROM OUR ARCHIVES

The Muon. Sheldon Penman; July 1961.

scientificamerican.com/magazine/sa

BIODIVERSITY

The Big Day

A Connecticut team races to find as many bird species as possible in 24 hours, in the high-intensity, low-stakes world of competitive birding

By Kate Wong

WHIMBREL is the 188th species the birders found on their Big Day.

Kate Wong is a senior editor for evolution and ecology at *Scientific American.*

ON A WARM DAY IN LATE APRIL, FRANK GALLO IS GETTING HIS STEPS in at one of his regular haunts: the sewage plant. He strolls along the paved trail outside the facility in Norwalk, Conn., scanning the pines on the left, the river on the right. Overhead eight Northern Rough-winged Swallows wheel in the cloudless sky, taking turns swooping into the water-treatment tanks to catch insects drawn to the nutrient-rich pools below. A Yellow Warbler belts out its not so humble brag—*sweet sweet sweet I'm so sweet.*

Gallo, a naturalist and birder, has been coming to the sewage plant regularly since last fall, when a motley crew of warblers—Prairie, Cape May, Tennessee, Palm, Pine and Yellow-rumped—that should have headed south for the winter decided to stay here instead. Birders flocked to the site all winter, trudging up and down the icy trail in hopes of glimpsing the rarities foraging in the tanks and evergreens. Now, with spring migrants starting to appear throughout the northeast, the sewage plant crowd is thinning. But Gallo keeps returning because he wants to see when the Cape May and Tennessee Warblers depart for their breeding grounds up north. Although overwintering in Connecticut was risky, the survivors are now that much closer to where they need to be to establish a territory for the summer, find a mate and reproduce. Maybe they'll get a head start, he muses. Such are the pleasures of birding—marveling at life's diversity, pondering the rhythms of the natural world, feeding curiosity one question at a time, even in unglamorous locations.

Today Gallo is preoccupied with his next avian pursuit. In just a few weeks he and five of his friends—some of the top birders in the state—will be doing their annual Big Day, competing as a team to find as many bird species in Connecticut as they can by sight or sound in a 24-hour period. They'll go midnight to midnight on a day of their choosing. Their goals: get 200 species, which no team in New England has ever been able to do; beat the existing New England record of 195 species, set by their archrivals in Massachusetts in 2014; best their own 2018 record of 193.

To accomplish any of these objectives, the team needs to figure out ahead of time where the hard-to-find birds are likely to be found. And it has to design a driving route that maximizes the number of sites the players can hit across the state and the amount of time they have at each one to see or hear the target species. Seconds count—there will be no pausing to admire one bird's dazzling plumage or another's melodious song, no studying a fascinating behavior or puzzling over an unexpected sighting. As a friend of his once quipped about Big Days, Gallo says, "This isn't birding. This is war."

"200 HAS TO BE A PERFECT DAY," team member Dave Tripp tells me. "To get 200, everything needs to be there and to call. It's doable, but all the stars need to line up." He and the other team members have been bringing those stars into alignment, and he is phoning to brief me. They've been honing their strategy since they first started birding together competitively more than a decade ago in New Jersey.

The most prestigious Big Day competition in the country is the World Series of Birding, held every year in New Jersey. For years the Connecticut team—it calls itself the Raven Lunatics—competed in the World Series, building its knowledge of New Jersey's birds and refining its tactics for getting as many of them as possible on game day. In 2008 the team took home the prize for the second-highest number of species, having found 222—an especially impressive feat considering they were from out of state. But in Connecticut, the Big Day record had been stuck at 186 species, set by another team in 1994. "Let's take what we've learned in Jersey and apply it to our home state," Tripp recalls telling the others. "Let's go for the state record in Connecticut."

Anyone can do a Big Day bird count following the American Birding Association's rules. Competitors have 24 hours—midnight to midnight on a single calendar day—to find as many bird species on the official checklist as they can; they may gather intelligence before

Kate Wong *(preceding pages, left);* **McPhoto Schaef** *Alamy Stock Photo (preceding pages, right)*

BIRDING TEAM (*left to right*) Patrick Dugan, Dave Provencher, Nick Bonomo, Dave Tripp, Frank Gallo and Fran Zygmont raced to find as many species in Connecticut as they could in 24 hours.

game day but cannot solicit outside information during the competition itself; species must be identified by eye or by ear with absolute certainty (no merely probable IDs allowed); they may play recordings of bird sounds judiciously to attract birds; at least 95 percent of the species listed on the final tally must have been detected by all the team members (up to 5 percent can be "dirty"—identified by some but not all participants), and team members must travel together in the same vehicle and remain within earshot of one another.

In 2009 the Raven Lunatics did their first Big Day in Connecticut and got 177 species—nine birds short of the long-standing state record. "It was late May, and we weren't getting enough," Tripp recalls. "We needed to get the stuff that breeds in boreal forest and tundra and was migrating through Connecticut, plus get the Connecticut breeders." May is the best month for a Big Day because it coincides with peak spring migration. But too late in the month and the waterfowl and other birds that overwintered in Connecticut will have departed for their breeding grounds in the Arctic and other northern locales. Too early and the birders will miss the warblers, flycatchers, vireos and other migrants making their way north from their wintering grounds.

In 2011 the team had a major breakthrough with 192 species, which smashed the state record and set a new bar for New England. A decade on, the Raven Lunatics remain the Connecticut record holders, having reached a new high of 193 species in 2018. But their New England victory was short-lived—days after their 2011 win their Massachusetts rivals surpassed them with 193 species. And in 2014 the Massachusetts team got 195 species, which, so far as the Raven Lunatics know, remains the largest number of bird species ever found in a single day in New England. "Massachusetts is bigger, with more habitat," Tripp is quick to note.

But although Connecticut is comparatively small, it has a variety of habitats, including grassland, forest, coast, and urban and suburban environments, explains Connecticut state ornithologist Margaret Rubega. It also occupies an important stretch of the Atlantic Flyway—a major thoroughfare for North American migratory birds. And it straddles the southernmost range of a number of northern birds and the northernmost range of southern ones. Consequently, the state hosts a surprisingly rich avian diversity—450 species at last count, compared with 507 in Massachusetts and 488 in New Jersey. More than half of those species breed here. The rest are mostly just passing through. Sometimes a vagrant species will show up, blown off course by a storm or lost as the result of a faulty internal compass.

The team must figure out how to hit as many sites as possible in a variety of habitats across the state and at the right times of day to find birds. Owls and marsh birds, for instance, call at night.

Kate Wong

Shorebirds in some locations are best observed near high tide, when the water concentrates them on exposed sandbars.

At the beginning of May, the players start scouting locations. Tripp runs the north. During the week he goes out at first light to search for birds for a few hours before heading to his job as deputy fire chief in Torrington. On weekends he optimizes the route, changing it as new scouting information comes in, sorting out which areas are must-visits and which he can cut so he can give the team more time in the south, where the birds members need are fewer and farther between.

Even with all of this preparation, key factors remain beyond the birders' control. The scouted birds may move or go quiet on the Big Day (nesting birds often stop singing). Migrants from the south may be waylaid by unfavorable weather. At the moment, Tripp tells me, it's looking like May 17, one week away, will be the day. It's the only date when all six team members can go, and the forecast doesn't show any weather that might move birds around. But any shift in the forecast between now and then could necessitate a change in plans, even if that means not everyone can go—including me.

The birders have agreed to let me tag along as they continue to scout bird locations across the state in the lead-up to the competition and to meet them at various points during the Big Day itself. After being cooped up for 15 months, I'm finally vaccinated and giddy at the prospect of getting out of the house to do some field reporting. I also have a keen personal interest in the subject matter. I started bird-watching in May 2020 as a means of pandemic escapism, first in my yard in Connecticut, then in neighboring towns. Now, a year in, I have 158 species on my state list. I can visually distinguish a Savannah Sparrow from a Song Sparrow, Hairy Woodpecker from Downy Woodpecker, Cooper's Hawk from Sharp-shinned Hawk (I think). I recognize the flutelike song of the Wood Thrush, the cacophonous call of the Willet, the Black-capped Chickadee's eponymous scold.

Still, I have years of practice to go before I can expect to walk out the door and confidently identify all the birds I encounter. Gallo, Tripp and their teammates, with decades of birding experience, know all the birds, whether they're juvenile or adult, in breeding plumage or nonbreeding plumage, singing an elaborate courtship song or just uttering a one-note call in flight. Nevertheless, I'm hard-pressed to see how they are going to find more bird species in a single day than I had in 365. "You have no idea what you're getting into," Tripp warns.

THREE DAYS LATER I meet team member Nick Bonomo at 8:30 in the morning at a carpool lot off Interstate 95 in the coastal town of Guilford. He's been looking for birds since 2 A.M. Game day is just a few days away, and he's behind on scouting his territory. Bonomo and Gallo run the southern part of the route, including the coast, with help from teammates Patrick Dugan and Dave Provencher. Today Bonomo, a physician assistant, is looking mainly for waterfowl, shorebirds and marsh birds, along with a few other species that the team wants to nail down in the south. I hop in his car, and we start working our way east, hitting one public access point after another along the crenulated shoreline.

We get off to a discouraging start. Neither the Brown Thrasher nor the White-eyed Vireo—secretive species that favor dense vegetation—shows up in the patch of coastal scrub where Bonomo was hoping to find them. A scan of the mud puddle near the fairgrounds fails to turn up the expected Solitary Sandpiper. "Before meeting you, I did have some luck," Bonomo says, explaining that he found waterbirds, including Surf Scoters, Red-throated Loons, Gadwalls, Hooded Mergansers and a Great Cormorant, earlier in the day. He has a long way to go, however. During the competition the team typically gets around a third of its birds in the south, most of which are coastal species.

It's a beautiful day, bright and breezy, a balm after the dark pandemic winter. But the glare from the sun and the waves from the wind, together with the heat shimmer, are making it tough to spot birds on the water. The next stop, a beachfront location, is more

GREAT-HORNED OWL (*fledgling, left*) and Cliff Swallow (*top*) cooperated on game day. But the team "dipped" on the Belted Kingfisher (*bottom*).

Jim Zipp *Science Source (opposite)*; **Ivan Kuzmin** *Alamy Stock Photo (top)*; **Brian Kushner** *Alamy Stock Photo (bottom)*

productive. Bonomo spies two small, sleek seabirds with black and white heads and bright yellow bills—Least Terns. This species, which nests on beaches, is threatened in Connecticut because of habitat loss. It's one of just two tern species the team can expect to find on competition day, the other being the Common Tern. Bonomo also notes a nearby flock of Dunlin, chunky little shorebirds with long, probing bills that breed in the Arctic tundra.

Surveying the water with his spotting telescope at the next beach, Bonomo discovers a Long-tailed Duck—an elegant sea duck with showy tail feathers—bobbing in the waves. Most Long-tailed Ducks have set off for their breeding grounds in the High Arctic by mid-May. During the competition "we only get this species 50 percent of the time," he says. On a distant outcropping, Bonomo spots a stocky bird with a dark bib—a Ruddy Turnstone, he announces. I have to take his word for it. Details of the bird, so named for its calico breeding plumage and the way it uses its stout bill to flip pebbles over in search of prey, are lost in the shadows, making identification impossible unless one knows exactly what to look for.

We continue east to a boat launch in the high marsh—a habitat that is vanishing in Connecticut because of sea-level rise caused by warming. As we pull in, a gang of Willets mobs a Northern Harrier, a slender hawk with a flashy white patch on its rump, driving it away. "Harrier is hard to get on a Big Day," Bonomo says. But it's the sparrows that he's most interested in. A Seaside Sparrow sings, unseen. And a few minutes later he scopes a Saltmarsh Sparrow—a striking, orange-faced bird—peeking out from the grass. Getting both marsh sparrows in one spot is a win for him, and I'm delighted to have gotten my first look at a Saltmarsh Sparrow. This species has declined by some 87 percent across its narrow range in the past 23 years as rising tides have flooded nests and drowned chicks.

Bonomo picks up some more sea ducks—Surf Scoters and Black Scoters—and a colony of Double-crested Cormorants nesting in trees on the way back to the carpool lot. He needs to get some sleep before he has to go out again. "It's physically unhealthy, not exercising, eating like crap" he says of the week leading up to the competition. "It's a damn good thing it's only one week a year."

The following day I join Gallo, who is also scouting in the southern part of the state. The afternoon starts with a bang. Gallo is driving by a city bridge to look for a Peregrine Falcon, a fast, fierce bird of prey that nests readily on human-made structures. It seems to me like a long shot, but as we pass by, a bird flies out from under the bridge. With only a brief glimpse to go on, I have no idea what it was, but Gallo thinks it could be a Peregrine based on the size. He circles back, and we get out of the car for a better look. I point out the concrete girder that I think the bird flew from. Gallo raises his binoculars to his eyes to scan, his movements smooth and precise as I fumble with my own bins. "Son of a bitch," he shouts a moment later. A nest box has been installed on the girder, and the Peregrine is sitting in it, plain as day. Gallo raises a hand for a high five. Raptors nest early in the breeding season and are attentive parents, so chances are good the bird will be here if the team drives by on competition day.

The rest of the afternoon is hit-or-miss. And the misses are weighing on Gallo. Here and there along the coast, he locates a few Sanderlings and Purple Sandpipers, Semipalmated Sandpipers and Least Sandpipers. But other species he needs—Black Skimmer, Pectoral Sandpiper and White-rumped Sandpiper, among others—elude him. "There's just no shorebirds right now. The weather pattern has not been conducive," Gallo says. "We want south winds with enough time for migrants to get here and blocking winds so they fall on Connecticut."

EASTERN MEADOWLARK, a species that is declining in Connecticut as grasslands dwindle, showed up on the Big Day.

Gallo calls Bonomo to check in and compare notes. Bonomo is sweating some of the marsh species. They don't have a Least Bittern, a small, hunched heron, pinned down yet. And they need the rails—reclusive birds that live in thick marsh grass—including the Sora, which can be tricky, and the Virginia Rail, which they can usually count on. "If we can't get Virginia Rail, we might as well call it a day and crack a beer," he says. But a check of the weather reveals a reason for a modicum of optimism about the missing migrants: variable winds are expected tonight, Bonomo notes, and "stuff will move on that."

I spend the next two mornings in northwestern Connecticut, the first one with Tripp, the next one with his teammate and best friend since grade school, Fran Zygmont. I'm on the road by 3 A.M. each day to meet them at 4:00 in Litchfield County, chugging coffee from a thermos and grumpily wondering why I, someone deeply committed to being sound asleep at this hour, decided to pursue this story.

For the purposes of the Big Day, the team birds the north differently than it does the south. In the south, where the targeted habitat is mostly open, the team identifies the majority of the birds by eye. In the north the players are searching mostly in forests and other closed habitats, often in the dark, so here they get the species primarily by ear. Although the early-morning temperatures are in the low 40s, Tripp and Zygmont drive with the windows down so they can hear the birds. Following their lead, I fasten my seat belt behind me so I can jump out of the car quickly at our frequent stops without the car dinging to remind me to buckle up.

Tripp is running the route, checking to make sure the birds he has scouted are still in the same place and trying to get the tim-

Jim Zipp *Science Source*

ing just right. At 4:36, he pulls over by a stand of pines that abut an open field and plays a recording of a Great Horned Owl from his cell phone through a Bluetooth speaker placed atop his car. To my amazement, a living shadow appears overhead, flying on silent wings to alight in the pines, and hoots in reply. Minutes later, somewhere in the field, an American Woodcock makes its nasal *peent* call. Tripp considers starting the route here if both species are present. "The thing that scares me is the Great-horned might eat the woodcock" he says.

By 4:57 the sky is brightening, and the dawn chorus is starting to fill the air. Tripp stops at one of his scouted locations and plays recordings of the Red-breasted Nuthatch and Brown Creeper—species the team needs to get in the north—but no birds respond. "We may need to push this stop back a bit," he says. "It's too early." Farther along the route, he hears the dry trill of the Dark-eyed Junco—another "must bird" in the north. But he's not getting any warblers. Like the nuthatch and the creeper, they're probably still asleep. For this stop, too, "we're a tad early," he decides. I stifle a yawn.

Sometimes a bird will give listeners only one note to go on. Pulling up to a creek, Tripp hears a chip—a type of call that many birds use to stay in contact with one another or to sound an alarm. "Louisiana Waterthrush," he declares. Of all the observation skills serious birders develop in pursuit of their hobby, this is the one that blows my mind. I can see how, with time, I'll be able to learn the field marks that identify birds visually. But memorizing the full vocal repertoires of these species, in all their variations, right down to the single-note chips and flight calls? That's a superpower.

Other birds make telltale sounds nonvocally. On a visit to a woodland swamp, we listen to the tapping of a woodpecker. Tripp explains that some of Connecticut's woodpecker species tap similarly, but this one is distinctive, starting out fast and then slowing down at the end of the sequence. "Yellow-bellied Sapsucker," he tells me. I thrill to the pro tip—this is a sound I can hear and remember.

The Ruffed Grouse, a ground-nesting bird that lives in dense forest, is also known for a nonvocal sound. The male will perch on a log or stump and perform a series of increasingly fast wingbeats, creating a deep thumping sound that starts off slowly and accelerates over the course of the 10-second display.

With the birds waking up and starting to sing and call, Tripp rattles off the species names as he hears them from the moving car. Black-capped Chickadee, Common Yellowthroat, Great Crested Flycatcher, Rose-breasted Grosbeak, Blue-headed Vireo, Red-eyed Vireo, Yellow-throated Vireo. Occasionally he points out other fauna: porcupines foraging on the side of the road, a bobcat—my first!—melting into the trees. I decide that being up this early has its benefits.

As the morning wears on, Tripp is pumped to locate at least three Cape May Warblers in a cluster of towering Norway spruces—a hard-to-get bird on a Big Day because it's finicky about habitat (the winter maverick at the Norwalk sewage plant notwithstanding). But some key species are proving worryingly difficult to secure. The Golden-crowned Kinglet—a tiny, frantic bird with a flaming crest and a very high-pitched song that dwells in coniferous forests—is nowhere to be found. Nor is the Eastern Meadowlark, a grassland songbird. And a visit to the bridge where he expected to find Cliff Swallows fails to turn up any sign of them. "Shit," he mutters, "that's not good."

The next morning with Zygmont brings more ups and downs. With the competition ostensibly just a day away, the team is glued to the weather and the radar-based bird-migration forecast maps. Team members are holding out hope for new migrants to arrive from the south—but they don't want the migrants they've already scouted to bail and continue north. In the spring, birds that habitually travel from their wintering grounds to another location to breed experience what's known as *zugunruhe*—a German word for migratory restlessness, Zygmont explains. Most land birds migrate at night, navigating by the moon and stars while the predators sleep. "They start one or two hours after dark, and then around 4 a.m. they drop in wherever they are and start feeding," he says. Intriguingly, this morning Zygmont has seen three birds in the road that didn't move when we drove by, which tells him they're exhausted—perhaps because they've been flying all night

Zygmont turns his attention to the species they still need buttoned up in the north. He's concerned about getting a Northern Saw-whet Owl, a tiny denizen of the woods. Leaning out the window of his red pickup, Zygmont whistles the bird's breeding call—a string of soft, monotone toots. “This is the only instrument I’ve ever played,” he says, gesturing toward his mouth. Zygmont and Dugan are the team’s vocalization wizzes. They can imitate the songs and calls of more than 100 bird species between them. No Saw-whets respond, but two Barred Owls hoot in the distance. The Saw-whets probably aren’t here because Barred Owls prey on them, he surmises.

It’s not enough to get one of each species scouted on the route, Zygmont explains, as the frenetic song of a Winter Wren wafts into the car. On game day, he says, “we can’t give that Winter Wren more than 30 seconds” to make its presence known. “So we need backups.”

The requirements are even more demanding for some of the harder-to-hear species. With the exception of Bonomo, the youngest of the group, the players are in their 50s and 60s. “Our hearing is dying,” Tripp says. Thus, for species that announce themselves at the highest and lowest frequencies—including the Golden-crowned Kinglet and Ruffed Grouse, respectively—Zygmont needs to find birds that are not only on the route but close enough to the road that everyone can hear them. The 95 percent rule looms large: should the players actually find 200 species on the Big Day, only 10 can be dirty.

At midnight on Monday, May 17, the team started its madcap scavenger hunt at an undisclosed location in the north. The team members swore me to secrecy for fear that their strategy could leak to competitors. Unable to join them there, I agreed to meet them at their next stop.

At 1:13 A.M., a black Chevy Suburban rolls into the parking lot of a Kohl’s department store. Six men wearing binoculars exit the vehicle and face the storefront, peering up at the mud nests built into its eaves. Cliff Swallows: check. Thirty seconds after they pulled in, the men pile back into their SUV and peel off into the night. They got exactly what they came for, nothing more, nothing less.

Unsure of exactly where we’re going next, I follow close behind, wondering what the speed limit is as we fly through the empty streets. I can’t lose them—Tripp, who’s driving, warned me at the outset that they cannot wait for me to catch up. At the next stops an Eastern Screech-Owl and Eastern Whip-poor-will call right on cue, and a surprise Yellow-billed Cuckoo and Green Heron chime in.

Tripp spontaneously cancels a planned stop at the gas station and heads for the pond where he scouted a pair of Common Gallinules—chickenlike rails with dark feathers and a candy corn bill—an uncommon find. We pull over on the side of the backcountry road and cut the engines. Under the faint light of the moon and stars the men fan out, cupping their hands around their ears to amplify the sounds of any birds. The twangy, plucked-banjo mating calls of green frogs punctuate the silence. Between the pond and the surrounding marsh and the forest beyond, the team stands to pick up several birds here. A distant Barred Owl is the first to sound off, hooting its signature *who cooks for you?* Then, in response to a recording, the elusive American Bittern makes its extraordinary display call—a series of bellowing gulps, as though it’s glugging a gallon of water—eliciting a hushed *YES!* from the birders. The gallinule cooperates, joined by a Marsh Wren, Swamp Sparrow and Virginia Rail.

When the birders wrap up the pond stop, at 2:28 A.M., they have a total of 22 species checked off their list. They're off to a good start—just 178 species and 22 hours to crack 200. I leave them to it and head home before we meet again in the afternoon, inviting them to text me with any highlights or lowlights. A text from Gallo awaits when I get home: word of a bear sighting, followed by a grainy photo of the creature lumbering in front of their car. "FOCUS, GALLO. THIS IS WAR," I reply, before drifting off to sleep.

The team wraps up the north at 9:36 A.M. with 124 species according to Zygmont, the keeper of the list, including the hard-won meadowlark, grouse and kinglet. "Average but hopeful," Gallo says of the number. The players are right on schedule. Tripp likes to be on the road headed south by 10 so they can use the driving time to get hawks, which come out around then to ride the rising thermal air currents.

DARK-EYED JUNCO (*top left*) and Golden-crowned Kinglet (*bottom left*) are birds the team has to get in the north. The Long-tailed Duck was a no-show in the south (*above*).

By the time I meet the group around 4 P.M. at Hammonasset Beach State Park in Madison—a major coastal birding destination in the south—the number is up to 176. The team is spread out on a viewing platform, hunched over spotting scopes. The sky is slightly overcast, the breeze gentle. Although they've been up for 16 hours, the players look bright-eyed and are in good spirits. They add Little Blue Heron, Clapper Rail, Ruddy Turnstone, Seaside Sparrow and Saltmarsh Sparrow to their list. Tripp, seeming more relaxed now that the north is done, rounds the guys up for a group photo. But it isn't long before Bonomo is prodding them to get a move on. They're in his territory now, and they have work to do.

Two hours and several stops later, the team is at 186 species—the number that held the state record for 17 years. The birders have nearly six hours left to find the 14 day birds and four night birds that are still in play, according to Gallo. It sounds doable, but at this point in the competition the new finds are scarce.

The birders have reached Milford Point, a barrier beach at the mouth of the Housatonic River. They lug their scopes up the observation tower's spiral staircase. "Is there a button we can push to get rid of all the Brant?" Bonomo jokes. Between the cloud cover and the glass-calm water, viewing conditions are great, but the small geese are everywhere. "Come on, ducks," Gallo urges, eager to see the Green-winged Teal and American Wigeon he found here the other day. The ducks have vanished, but Dugan discovers a Yellow-crowned Night-Heron, and Gallo and Bonomo get two Whimbrels, large, leggy shorebirds with long, decurved bills. Scanning a distant flock, Gallo notices a single reddish bird. "I think I have a Red Knot," he calls out. A cinnamon-breasted sandpiper that is declining rapidly as humans overharvest the horseshoe crabs whose eggs it depends on for food, the Red Knot is a bird the team does not always get on a Big Day. The others quickly shift to see. Bonomo locates the bird in his scope and studies it, trying to rule out other possibilities. It's very plump, a hair larger than a Dunlin, he observes. "It's a knot," Gallo confirms. "Everyone get that?" When I take my leave of the birders, they are departing Milford Point with 189 species—and a shot at breaking their record.

They nab the wigeon and a Wilson's Warbler at the next two stops, bringing them to 191. At 10:33 P.M. Gallo texts to say they heard a King Rail, a state-endangered bird scouted earlier by honorary team member Phil Rusch—and are heading back north to the finish line. The rail is the last bird they get for their Big Day, number 192.

Later that week, after everyone has caught up on sleep, I gather the birders for pizza and beer to recap the "hotwash," a name Tripp borrowed from emergency response lingo for their evaluation of the event. The mood is celebratory. Although they did not set any new records, the birders tied their second-highest score—under tough conditions—and raised an estimated $1,300 for the Roaring Brook Nature Center in Canton to help support the animals in its care. Thirteen of the species the players had scouted, including the Cape May Warbler and Long-tailed Duck, were no-shows, along with the Common Nighthawk, which they usually happen upon at dusk on a Big Day. And unscouted birds that they often catch migrating on game day did not materialize. "This migration is the worst one in years," Bonomo says.

Still, "it was a very clean run," Provencher observes. The route—all 478 miles of it—was tight and efficiently executed, Gallo notes, with only one delay for a Blue-winged Teal, which took 27 minutes to get. What is more, only six of the 192 birds they got were dirty. Bonomo says he is confident that given how well they did in a lousy migration year, 200 is within their grasp.

"One day it will all come together," Gallo says. "The birds we scouted will all stick, and the migrants will drop in, and all will be right with the world." Until they decide they need to go for 201. SA

FROM OUR ARCHIVES

How Birds Branched Out. Kate Wong; November 2020.

scientificamerican.com/magazine/sa

Jim Zipp *Science Source;* **Markus Varesvuo** *Nature Picture Library;* **All Canada Photos** *Alamy Stock Photo (clockwise from top left)*

SUSTAINABILITY

MORE FOOD,

LESS WASTE

Cutting losses across the food chain could vastly increase supply and significantly reduce carbon emissions

By Chad Frischmann and Mamta Mehra
Graphics by Valentina D'Efilippo

Chad Frischmann is co-author, lead researcher and creator of the Drawdown Solutions Framework at Project Drawdown, an international research group focused on solving climate change.

Mamta Mehra is a senior fellow for the land-use and food sectors at Project Drawdown.

IMAGINE GOING TO THE MARKET, LEAVING WITH THREE FULL BAGS OF GROCERIES AND COMING HOME. Before you step through your door, you stop and throw one of the bags into a trash bin, which later is hauled away to a landfill. What a waste. Collectively, that is exactly what we are doing today. Globally, 30 to 40 percent of food intended for human consumption is not eaten. Given that more than 800 million people go hungry every day, the scale of food loss fills many of us with a deep sense of anguish.

If population growth and economic development continue at their current pace, the world will have to produce 53 million more metric tons of food annually by 2050. That increase would require converting another 442 million hectares of forests and grassland—far greater than the size of India—into farmland over the next 30 years. The escalation would also release the equivalent of an additional 80 billion tons of carbon dioxide over the next 30 years—about 15 times the emissions of the entire U.S. economy in 2019. Food waste already accounts for roughly 8 percent of the world's greenhouse gases.

There is another path, however. Our group at Project Drawdown, an international research and communications organization, completed an exhaustive study of existing technologies and practices that can significantly reduce greenhouse gas levels in the atmosphere while ushering in a more regenerative society and economy. Reducing food waste is one of the top-five means of achieving these goals among 76 we analyzed. Basic adjustments in how food is produced and consumed could help feed the entire world a healthy, nutrient-rich diet through 2050 and beyond without clearing, planting or grazing more land than is used today. Providing more food by eliminating waste, along with better ways of producing that food, would avoid deforestation and also save an enormous amount of energy, water, fertilizer, labor and other resources.

Opportunities to reduce waste exist at every step along the supply chain from farm to table. We harvest crops, raise livestock, and process these commodities into products such as rice, vegetable oil, potato chips, perfectly cut carrots, cheese and New York strip steaks. Most of these products are packaged in cardboard boxes, plastic bags and bottles, tin cans and glass jars made from extracted materials in industrial factories, and then they are shipped on gas-guzzling trucks, trains and planes all over the world.

After arriving at stores and restaurants, food is held in energy-hungry refrigerators and freezers that use hydrofluorocarbons—powerful greenhouse gases—until purchased by consumers, whose eyes are often bigger than their appetites, particularly in richer communities. In high-income countries, restaurants and households turn on their energy-consuming stoves and ovens, and in developing nations, billions of people burn biomass in noxious cookstoves that spew polluting, unhealthy smoke and black carbon.

After all these waste-producing activities, too much of the food that makes it to a consumer's table is thrown in the garbage, which then is typically transported by fossil-fueled trucks to landfills where it decomposes and emits methane, another potent greenhouse gas. Tossing that leftover lasagna accounts for far more emissions than a rotting tomato that never leaves the farm gate. We can do better.

SMALLER FOODPRINT

AT PROJECT DRAWDOWN, we poured global data from the Food and Agriculture Organization and many other sources into a detailed model of the entire food production and consumption system. The model took into account rising population projections, as well as greater consumption and more meat eating per person, particularly in developing countries, based on actual trends over the past several decades. According to our calculations, healthier diets and more regenerative agricultural production lead to a lower "foodprint"—less waste, fewer emissions and a cleaner environment.

If half of the world's population consumes a healthy 2,300 kilocalories a day, built around a plant-rich diet, and puts into practice already proven actions that cut waste across the supply chain, food losses could decline from the current 40 percent to 20 percent, an incredible savings. If we were even more ambitious in following the same practices, food waste could be cut to 10 percent [*see graphics on pages 77–80 for details*].

These hefty savings would result partly from shifts in basic habits. In the developed world, embracing an average daily 2,300-kilocalorie diet instead of consumption that often reaches more than 3,000 kilocalories lessens food waste in the first place. In the developing world, caloric and protein intake generally need to rise to reach nutritious levels, which may increase some waste across the system. But overall, if everyone on the planet adopted healthy consumption practices and a plant-rich (not necessarily vegetarian) diet, 166 million metric tons of food waste could be avoided over the next 30 years. Feedback would be sent across the supply chain

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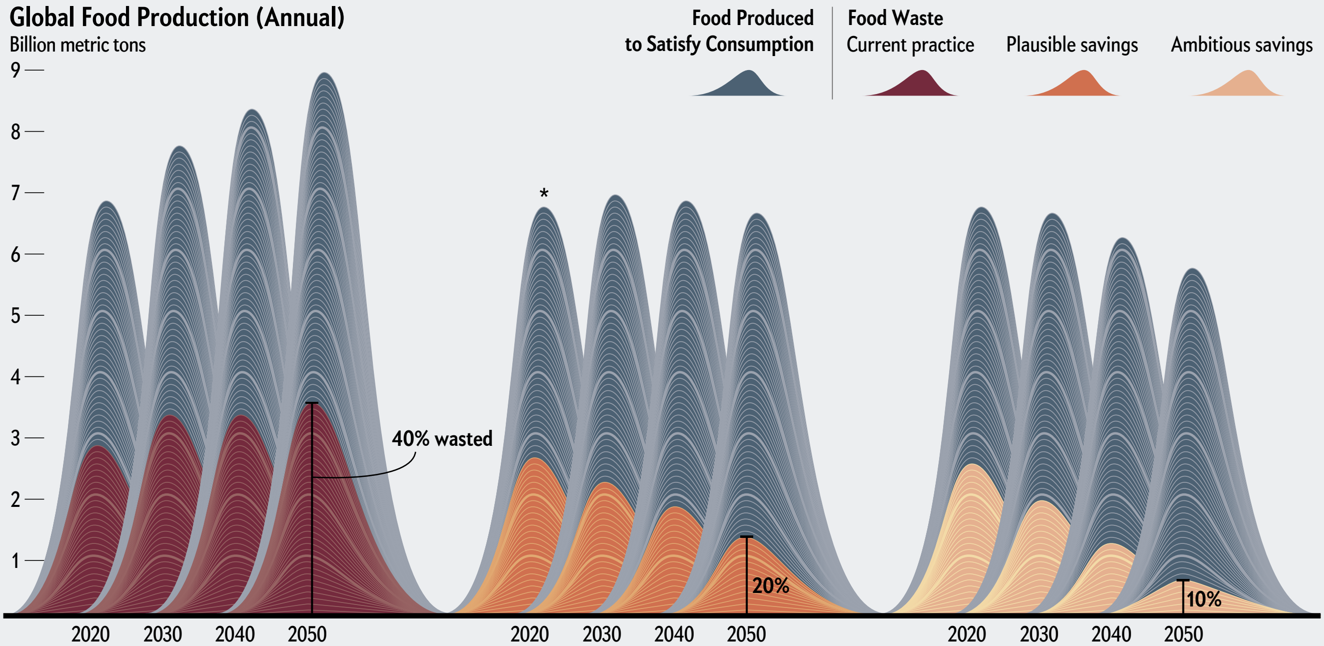
fcafotodigital *Getty Images (preceding pages)*

Piles of Food Wasted Worldwide

A troubling **40 percent of food produced** is lost across the supply chain from farm to table. A basic shift toward lessening excessive consumption and toward more plant-based diets, while also applying waste-saving practices at every step, could cut losses dramatically. Such measures would provide food for millions of people who go hungry and greatly reduce water depletion, energy use and carbon emissions.



CURRENT PRACTICE

This baseline scenario assumes that global population and consumption per person continue to rise as they have over the past several decades; 40 percent of food produced is wasted.

PLAUSIBLE SAVINGS

If half the world's people consume 2,300 kilocalories a day and choose more plants and less meat, and losses are reduced across the supply chain, waste could be cut to 20 percent by 2050.

AMBITIOUS SAVINGS

If three quarters of Earth's population follows the same measures described in the "plausible" scenario, waste could drop to 10 percent.

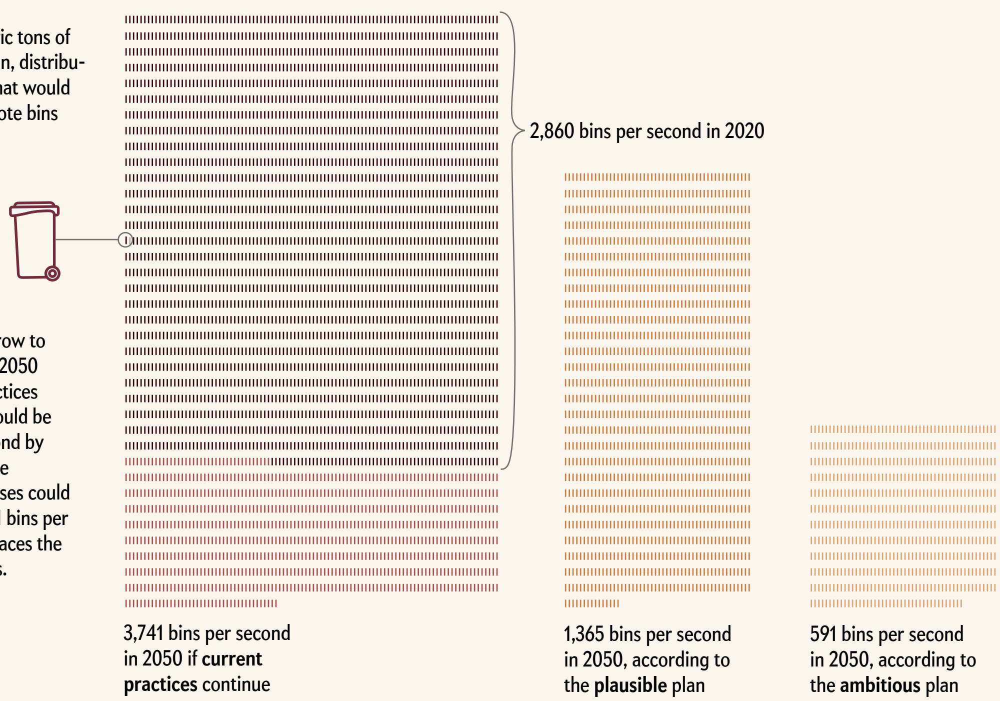
** Projections begin with 2018, so 2020 values are slightly different for each scenario.*

Trashed: Every Second the World Wastes 2,860 Garbage Bins of Food

Each year 2.7 billion metric tons of food are lost in production, distribution and consumption. That would fill 2,860 curbside trash tote bins every second.

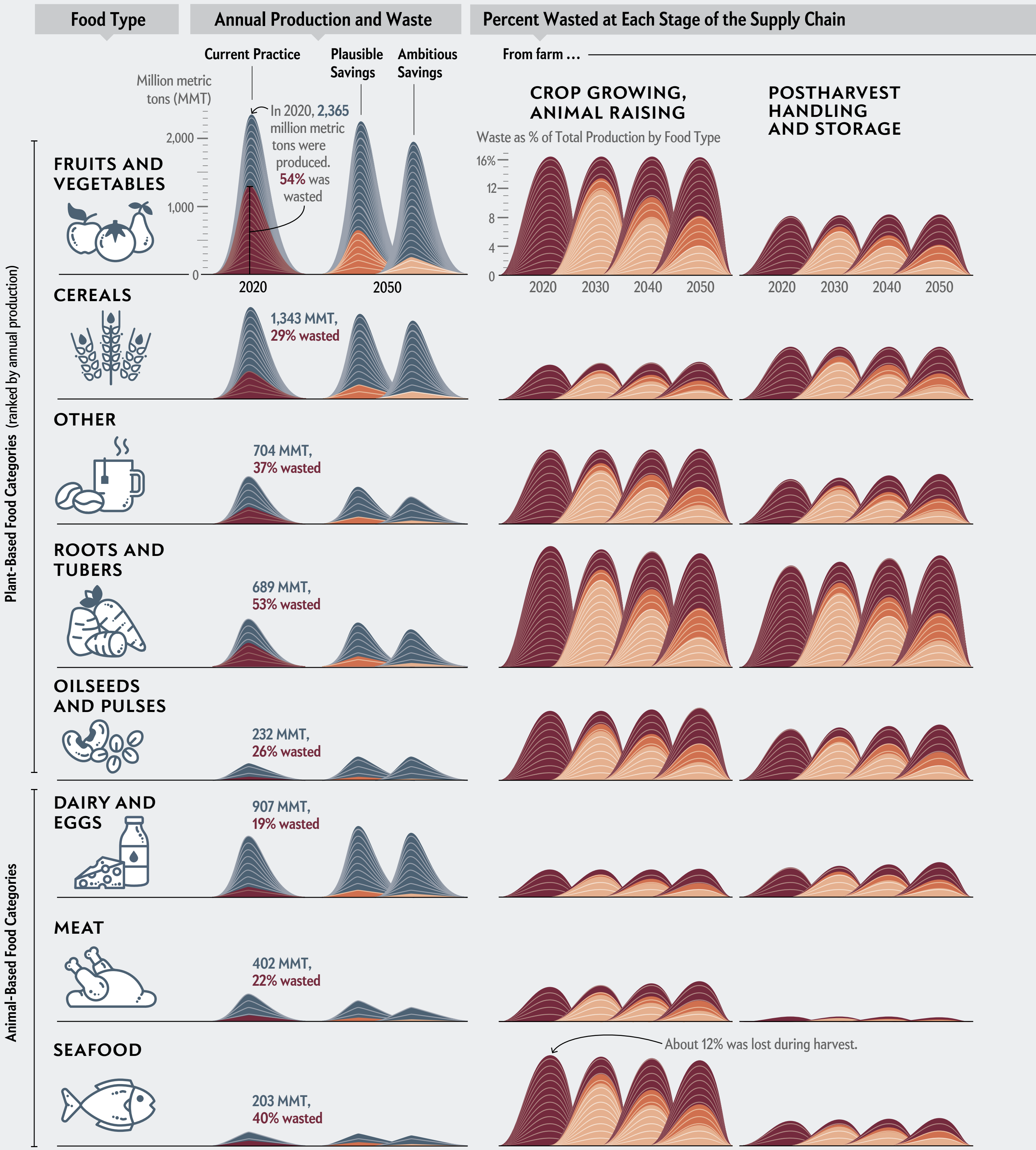
Household curbside bin
30 kilograms of waste

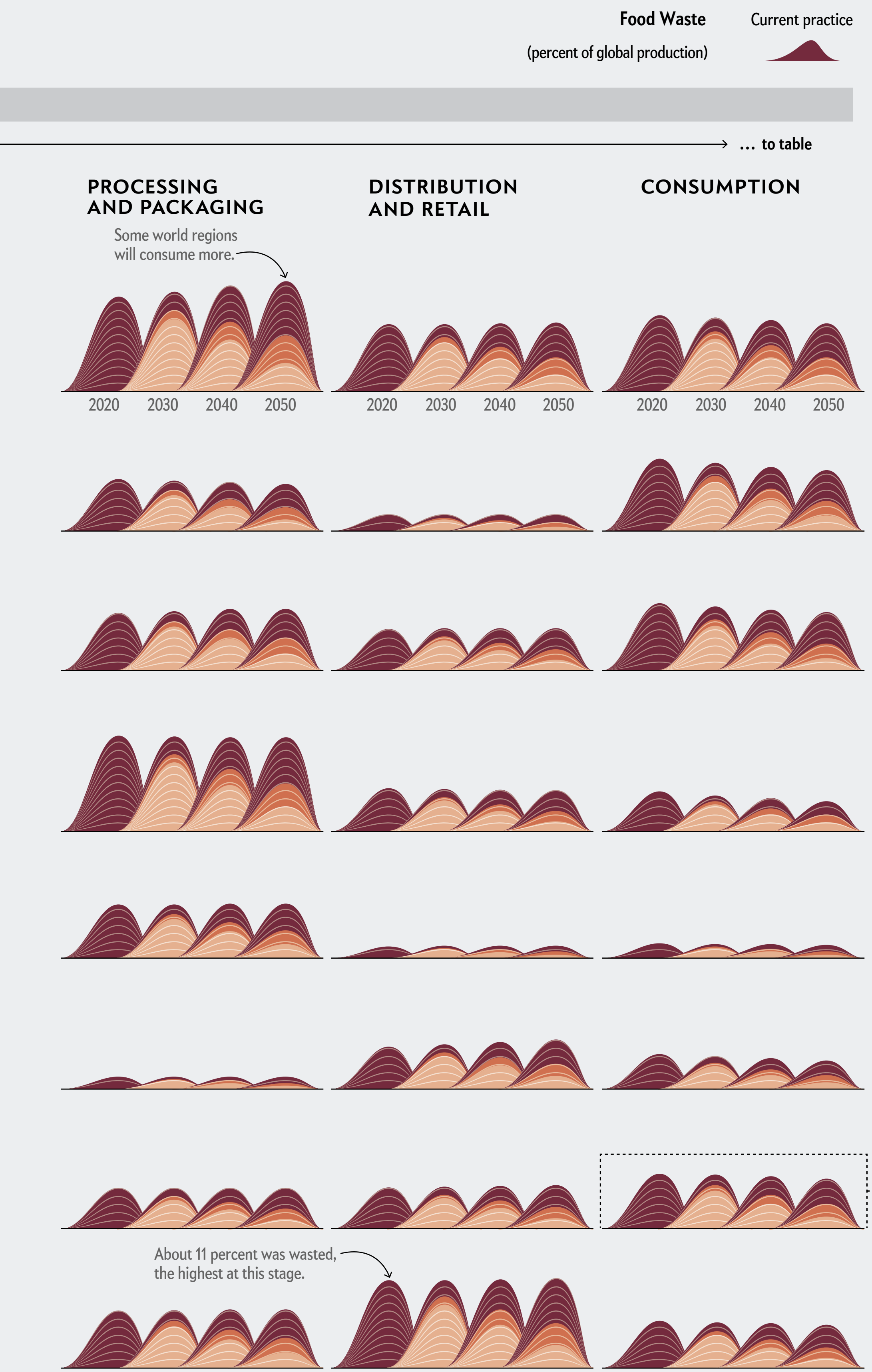
Losses are expected to grow to 3,741 bins per second by 2050 if current trends and practices continue. That amount could be cut to 1,365 bins per second by 2050 if the set of plausible solutions is achieved. Losses could be further reduced to 591 bins per second if the world embraces the set of ambitious solutions.



Food Lost, and Possible Reductions, across the Supply Chain

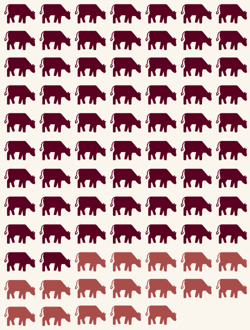
Plant and animal food intended for human consumption is lost across every stage of the supply chain, from field to fork. The numbers here are global averages, but in low-income countries, more waste occurs in the early stages, such as farming and storage. In high-income countries, more waste happens in the late stages, notably markets, restaurants and homes. Solutions will therefore vary by location.





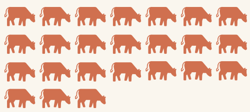
How Much Meat Is Wasted?

Every minute the world wastes the equivalent weight of **65 cows** of meat at home.



Losses would rise to **82 cows** a minute by 2050 if current practices continue.

Waste in 2050 could be reduced to **24 cows** under the plausible plan ...



... and down to **8 cows** in the ambitious plan.


Adult cow, average weight 800 kilograms

Carbon Emissions Avoided

If global population, consumption per person and waste along the supply chain continue according to recent trends, the world will emit huge amounts of greenhouse gases related to food. It will also have to clear more land to cultivate, which creates additional emissions and shrinks forests and grasslands that could absorb atmospheric carbon dioxide. Changes under the plausible and ambitious scenarios would greatly reduce emissions.

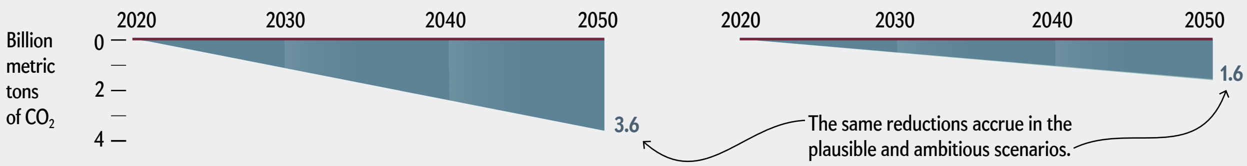
Annual CO_2 Emissions
- Current practices continue
- Plausible scenario
- Ambitious scenario

EMISSIONS REDUCTIONS BECAUSE OF ...

... LAND CONVERSION AVOIDED

Compared with current practices continuing through 2050, less food waste and shifting to a plant-rich diet in the plausible and ambitious scenarios would allow the world to produce enough food on current cropland. Not clearing more land would avoid billions of tons of carbon emissions.

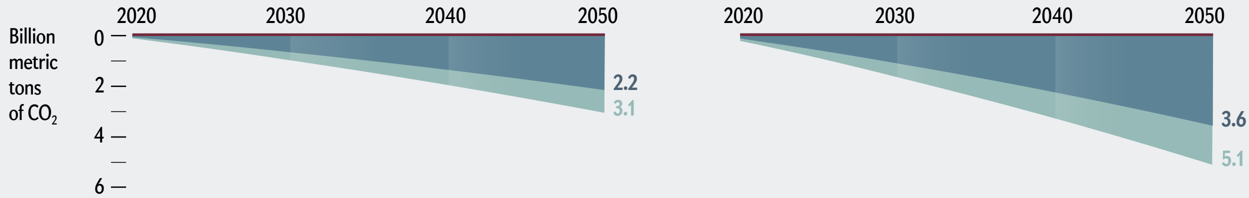
Resulting from Less Food Waste | **Resulting from Shift to Plant-Rich Diet**



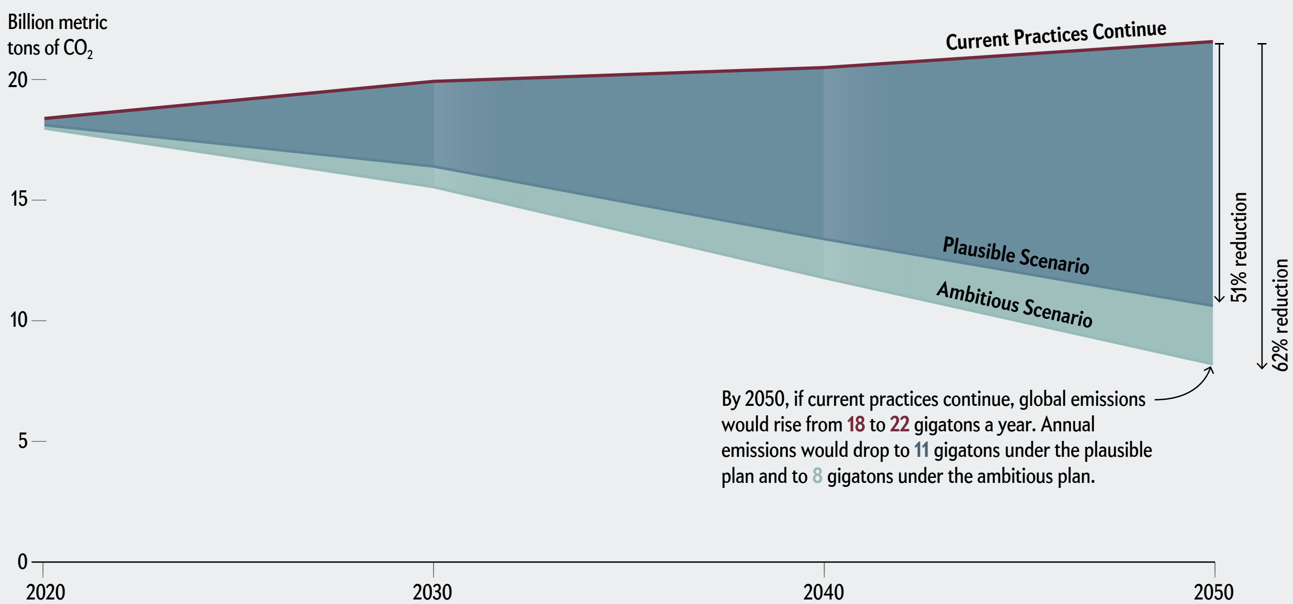
... BETTER AGRICULTURAL PRODUCTION

Greater production efficiencies under regenerative farming practices in the plausible and ambitious scenarios would further reduce emissions related to less food waste and a shift to a plant-rich diet.

Resulting from Less Food Waste | **Resulting from Shift to Plant-Rich Diet**



TOTAL CO_2 EMISSIONS REDUCTIONS FROM CHANGES ABOVE (ANNUAL)



Continued from page 76
to increase crop production and decrease animal production.

Reducing waste by adjusting how food is produced and consumed can greatly help the environment as well. Different types of foods such as grains, vegetables, fish, meat and dairy have very different environmental footprints. On average, growing and harvesting one kilogram of tomatoes creates about 0.35 kilogram of carbon dioxide emissions. Producing the same amount of beef creates an average of 36 kilograms of emissions. With the entire supply chain taken into account, greenhouse gas emissions from plant-based commodities are 10 to 50 times lower than from most animal-based products.

Additionally, industrial agriculture has spread monocropping, excessive tillage, and widespread use of synthetic fertilizers and pesticides. These practices degrade soil and emit a vast amount of greenhouse gases. Staples are still destroyed in the field by pests and disease and can rot in storage. Livestock consumption of grasses and feed adds further emissions.

Agroecological pest-management practices, such as planting different crops together, and smarter crop rotation can suppress pests and weeds, reducing these losses. Improved livestock-management practices, such as silvopasture, which integrates trees into foraging land, can improve the quality and quantity of animal-based products: more food from fewer hooves in the field and thus fewer resources used and fewer losses. And because regenerative farming practices—which can increase yield from 5 to 35 percent, restore soils and pull more carbon from the air—use compost and manure instead of artificial fertilizers, any food that fails to leave the farm gate can be recycled as natural fertilizer or can be converted by anaerobic digestors into biogas for energy on the farm. More farms need to convert to such practices. Restaurants across the U.S. are helping them through one interesting organization called Zero Foodprint, started by chef Anthony Myint, which takes a few cents added to patrons' bills to fund regenerative farms in the making.

SAVING THE THIRD BAG

IN LOW-INCOME COUNTRIES, most food is lost before ever getting to market. Improving education and professional training for farmers and producers there, along with innovative technologies, can minimize waste. India's state of Jharkhand, for example, has installed solar-powered refrigeration units that allow farmers who produce vegetables, fruits and other perishables to store their products without sacrificing quality—a project led by the United Nations Development Program and the Global Environment Facility. In Africa, the Consortium of International Agricultural Research Centers has expanded training that will help local farmers grow more food under conditions being created by climate change, using crops that better tolerate drought and no-till farming to protect withering soil.

In high- and medium-income countries, most waste occurs at the end of the supply chain—markets and households. There consumers have a tremendous amount of power to prevent waste. A good first step is to reflect on what and how much we are buying. This begins with conscious decisions to purchase what we intend to eat and to eat what we purchase. Rather than overstocking on perishables and other products, buying appropriate quantities of food reduces waste. If too much is cooked for the dinner table, properly storing leftovers reduces spoilage, or they can be shared with neighbors, building stronger community ties.

Broader cultural shifts are also required. The "inglorious fruits and vegetables" campaign launched by the French supermarket chain Intermarché in 2014 aimed to avoid waste by changing cultural attitudes toward "imperfect" foods. Markets tend to procure only fruits and vegetables that meet an idealized cultural perception of shape and color. Imperfect produce that does not match these false traits accounts for up to 40 percent of edible fruits and vegetables being discarded before they leave the farm gate. Instead Intermarché sells these fruits and vegetables in special aisles and runs a national marketing campaign glorifying the inglorious. Other retailers are going even further: All the shelves at Danish supermarket WeFood are stocked with products that would have gone to a landfill. Pittsburgh-based 412 Food Rescue distributes nutritious food that was destined for landfills because of imperfections, limited freshness (such as day-old bread) and unclear labeling to communities in need—for free.

Wholesalers, retailers and restaurants can play a significant role in shrinking the waste piles. They can demand that suppliers use more food from local regenerative farms. Ensuring that food items are sold with clear, standardized "sell by/use by" labels helps store managers know when to mark down items, and it helps consumers know when and when not to dispose of food. Restaurant owners can offer different portion sizes and fewer menu items and can encourage patrons to take leftovers home.

Governments and companies that offer food services to employees can jump in, too. U.S. federal government cafeterias serve more than two million people; imagine if the kitchen managers chose to offer plant-rich fare made from perfectly imperfect produce procured from regenerative suppliers. Google is already doing more of that in its cafeterias today.

No matter how conscientious we all are, some food will inevitably be lost across the supply chain. Anaerobic digesters and composting are better ways of disposal than dumping food in landfills because they create soil or generate electricity. Eight states across the U.S. now have laws requiring that organic waste be diverted from landfills to avoid potent methane emissions. The latest Project Drawdown analysis shows that implementing these solutions globally can reduce greenhouse gas emissions by around 14 billion metric tons over the next 30 years.

The real magic happens when a variety of solutions are adopted in parallel and sustained over time. The decisions people make as farmers, executives, grocers, chefs and consumers can prevent enough food loss to feed the world through 2050 without converting any more land. That means together we can eliminate hunger and support a healthier global population. And there would still be enough cropland available to grow plants for organic materials such as bioplastics, insulation and biofuels.

Revamping the food chain and adjusting eating habits will not happen overnight. Nor should we expect to immediately become perfect, regeneratively minded, plant-rich connoisseurs who are fastidious about our purchases and what we waste. Our most fundamental task is to be conscientious about the choices we make—to try to be "solutionists" as much as we can. Together we can save that third bag of groceries. SA

FROM OUR ARCHIVES

The Biomass Bottleneck. Eric Toensmeier and Dennis Garrity; August 2020.

scientificamerican.com/magazine/sa

THEORETICAL PHYSICS

The Artificial Physicist

A machine-learning system is making shocking progress at the frontiers of experimental quantum physics

By Anil Ananthaswamy

Illustration by Kotryna Zukauskaite

QUANTUM PHYSICIST MARIO KRENN REMEMBERS sitting in a café in Vienna in early 2016, poring over computer printouts, trying to make sense of what MELVIN had found. MELVIN was a machine-learning algorithm Krenn had built, a kind of artificial intelligence. Its job was to mix and match the building blocks of standard quantum experiments and find solutions to new problems. And it did find many interesting ones. But there was one that made no sense. "The first thing I thought was, 'My program has a bug because the solution cannot exist,'" Krenn says.

MELVIN had seemingly solved the problem of creating highly complex entangled states involving multiple photons (entangled states being those that once made Albert Einstein invoke the specter of "spooky action at a distance"). Krenn, Anton Zeilinger of the University of Vienna and their colleagues had not explicitly provided MELVIN the rules needed to generate such complex states, yet it had found a way. Eventually Krenn realized that the algo-

Anil Ananthaswamy is author of *The Edge of Physics, The Man Who Wasn't There* and, most recently, *Through Two Doors at Once: The Elegant Experiment That Captures the Enigma of Our Quantum Reality.*

rithm had rediscovered a type of experimental arrangement that had been devised in the early 1990s. But those experiments had been much simpler. MELVIN had cracked a far more complex puzzle. "When we understood what was going on, we were immediately able to generalize [the solution]," says Krenn, who is now at the University of Toronto.

Since then, other teams have started performing the experiments identified by MELVIN, allowing them to test the conceptual underpinnings of quantum mechanics in new ways. Meanwhile Krenn, working with colleagues in Toronto, has refined their machine-learning algorithms. Their latest effort, an AI called THESEUS, has upped the ante: it is orders of magnitude faster than MELVIN, and humans can readily parse its output. While it would take Krenn and his colleagues days or even weeks to understand MELVIN's meanderings, they can almost immediately figure out what THESEUS is saying. "It is amazing work," says theoretical quantum physicist Renato Renner of the Institute for Theoretical Physics at the Swiss Federal Institute of Technology Zurich, who reviewed a 2020 study about THESEUS but was not directly involved in these efforts.

Krenn stumbled on this entire research program somewhat by accident when he and his colleagues were trying to figure out how to experimentally create quantum states of photons entangled in a very particular manner. When two photons interact, they become entangled, and both can be mathematically described only using a single shared quantum state. If you measure the state of one photon, the measurement instantly fixes the state of the other even if the two are kilometers apart (hence Einstein's derisive comments on entanglement being "spooky").

In 1989 three physicists—Daniel Greenberger, the late Michael Horne and Zeilinger—described an entangled state that came to be known as GHZ (after their initials). It involved four photons, each of which could be in a quantum superposition of, say, two states, 0 and 1 (a quantum state called a qubit). In their paper, the GHZ state involved entangling four qubits such that the entire system was in a two-dimensional quantum superposition of states 0000 and 1111. If you measured one of the photons and found it in state 0, the superposition would collapse, and the other photons would also be in state 0. The same went for state 1. In the late 1990s Zeilinger and his colleagues experimentally observed GHZ states using three qubits for the first time.

Krenn and his colleagues were aiming for GHZ states of higher dimensions. They wanted to work with three photons, where each photon had a dimensionality of three, meaning it could be in a superposition of three states: 0, 1 and 2. This quantum state is called a qutrit. The entanglement the team was after was a three-dimensional GHZ state that was a superposition of states 000, 111 and 222. Such states are important ingredients for secure quantum communications and faster quantum computing. In late 2013 the researchers spent weeks designing experiments on blackboards and doing the calculations to see if their setups could generate the required quantum states. But each time they failed. "I thought, 'This is absolutely insane. Why can't we come up with a setup?'" Krenn says.

To speed up the process, Krenn first wrote a computer program that took an experimental setup and calculated the output. Then he upgraded the program to allow it to incorporate in its calculations the same building blocks that experimenters use to create and manipulate photons on an optical bench: lasers, nonlinear crystals, beam splitters, phase shifters, holograms, and the like. The program searched through a large space of configurations by randomly mixing and matching the building blocks, performed the calculations and spat out the result. MELVIN was born. "Within a few hours the program found a solution that we scientists—three experimentalists and one theorist—could not come up with for months," Krenn says. "That was a crazy day. I could not believe that it happened." Then he gave MELVIN more smarts. Anytime it found a setup that did something useful, MELVIN added that setup to its toolbox. "The algorithm remembers that and tries to reuse it for more complex solutions," Krenn says.

It was this more evolved MELVIN that left Krenn scratching his head in a Viennese café. He had set it running with an experimental toolbox that contained two crystals, each capable of generating a pair of photons entangled in three dimensions. Krenn's naive expectation was that MELVIN would find configurations that combined these pairs of photons to create entangled states of at most nine dimensions. But "it actually found one solution, an extremely rare case, that has much higher entanglement than the rest of the states," Krenn says.

Eventually he figured out that MELVIN had used a technique that multiple teams had developed nearly three decades ago. In 1991 Xin Yu Zou, Li Jun Wang and Leonard Mandel, all then at the University of Rochester, designed one method. And in 1994 Zeilinger, then at the University of Innsbruck in Austria, and his colleagues came up with another. Conceptually these experiments attempted something similar, but the configuration that Zeilinger and his colleagues devised is simpler to understand. It starts with one crystal that generates a pair of photons (A and B). The paths of these photons go right through another crystal, which can also generate two photons (C and D). The paths of photon A from the first crystal and of photon C from the second overlap exactly and lead to the same detector. If that detector clicks, it is impossible to tell whether the photon originated from the first or the second crystal. The same goes for photons B and D.

A phase shifter is a device that effectively increases the path a photon travels as some fraction of its wavelength. If you were to introduce a phase shifter in one of the paths between the crystals and kept changing the amount of phase shift, you could cause constructive and destructive interference at the detectors. For example, each of the crystals could be generating, say, 1,000 pairs of photons per second. With constructive interference, the detectors would register 4,000 pairs of photons per second. And with destructive interference, they would detect none: the system as a whole would not create any photons even though individual crystals would be generating 1,000 pairs a second. "That is actually quite crazy, when you think about it," Krenn says.

MELVIN's funky solution involved such overlapping paths. What had flummoxed Krenn was that the algorithm had only two crystals in its toolbox. And instead of using those crystals at the beginning of the experimental setup, it had wedged them inside an interferometer (a device that splits the path of, say, a photon into two and then recombines them). After much effort, he realized that the setup MELVIN had found was equivalent to one involving more than two crystals, each generating pairs of photons, such that their paths to the detectors overlapped. The configuration could be used to generate high-dimensional entangled states.

Quantum physicist Nora Tischler, who was a Ph.D. student working with Zeilinger on an unrelated topic when MELVIN was being put through its paces, was paying attention to these developments. "It was kind of clear from the beginning [that such an] experiment wouldn't exist if it hadn't been discovered by an algorithm," she says.

Besides generating complex entangled states, the setup using more than two crystals with overlapping paths can be employed to perform a generalized form of Zeilinger's 1994 quantum interference experiments with two crystals. Aephraim Steinberg, an experimentalist who is a Toronto colleague of Krenn's but has not worked on these projects, is impressed by what the AI found. "This is a generalization that (to my knowledge) no human dreamed up in the intervening decades and might never have done," he says. "It's a gorgeous first example of the kind of new explorations these thinking machines can take us on."

In one such generalized configuration with four crystals, each generating a pair of photons, and overlapping paths leading to four detectors, quantum interference can create situations where either all four detectors click (constructive interference) or none of them do so (destructive interference). Until recently, carrying out such an experiment had remained a distant dream. Then, in a March preprint paper, a team led by Lan-Tian Feng of the University of Science and Technology of China, in collaboration with Krenn, reported that they had fabricated the entire setup on a single photonic chip and performed the experiment. The researchers collected data for more than 16 hours: a feat made possible because of the photonic chip's incredible optical stability, something that would have been impossible to achieve in a larger-scale tabletop experiment. For starters, the setup would require a square meter's worth of optical elements precisely aligned on an optical bench, Steinberg says. Besides, "a single optical element jittering or drifting by a thousandth of the diameter of a human hair during those 16 hours could be enough to wash out the effect," he says.

During their early attempts to simplify and generalize what MELVIN had found, Krenn and his colleagues realized that the solution resembled abstract mathematical forms called graphs, which contain vertices and edges and are used to depict pairwise relations between objects. For these quantum experiments, every path a photon takes is represented by a vertex. And a crystal, for example, is represented by an edge connecting two vertices. MELVIN first produced such a graph and then performed a mathematical operation on it. The operation, called perfect matching, involves generating an equivalent graph in which each vertex is connected to only one edge. This process makes calculating the final quantum state much easier, although it is still hard for humans to understand.

That changed with MELVIN's successor THESEUS, which generates much simpler graphs by winnowing the first complex graph representing a solution that it finds down to the bare minimum number of edges and vertices (such that any further deletion destroys the setup's ability to generate the desired quantum states). Such graphs are simpler than MELVIN's perfect matching graphs, so it is even easier to make sense of any AI-generated solution. Renner is particularly impressed by THESEUS's human-interpretable outputs. "The solution is designed in such a way that the number of connections in the graph is minimized," he says. "And that's naturally a solution we can better understand than if you had a very complex graph."

Eric Cavalcanti of Griffith University in Australia is both impressed by the work and circumspect about it. "These machine-learning techniques represent an interesting development. For a human scientist looking at the data and interpreting it, some of the solutions may look like 'creative' new solutions. But at this stage, these algorithms are still far from a level where it could be said that they are having truly new ideas or coming up with new concepts," he says. "On the other hand, I do think that one day they will get there. So these are baby steps—but we have to start somewhere." Steinberg agrees. "For now they are just amazing tools," he says. "And like all the best tools, they're already enabling us to do some things we probably wouldn't have done without them." SA

FROM OUR ARCHIVES

Crossing the Quantum Divide. Tim Folger; July 2018.

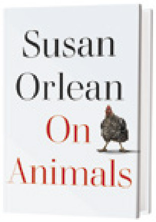
scientificamerican.com/magazine/sa

NONFICTION

Animal Person

Our mechanistic relationships with nonhuman animals

Review by Lydia Millet



On Animals
By Susan Orlean.
Avid Reader Press/
Simon & Schuster,
2021 ($28)

In *On Animals*, a new collection of old essays, veteran journalist Susan Orlean is almost the obverse of wonder-seeking naturalists like David Attenborough. Her focus is not on wild creatures and their swiftly disappearing worlds but on animals that live in human-dominated spheres: pets, working animals, and those kept as barnyard companions, livestock, or curiosities. Her subjects are the familiar denizens of the home, farm, zoo and marketplace.

Orlean explores the human machinations around show dogs and celebrity megafauna such as captive giant pandas and the movie star orca Keiko of *Free Willy* fame. She tells the unsettling saga of an American woman who kept numerous tigers, written long before the airing of the notorious series *Tiger King*. The differences between mules and donkeys are illuminated here, as are the decline and fall of pack animals in the armed forces and the poignancy of a young girl's devotion to her homing pigeons.

Orlean deftly captures some of the ways in which categories like "pet" and "revenue source" or "food" overlap, sometimes painfully. And how in other cases, such as donkeys in Morocco's medinas, working animals are seen as machines and unmourned when, after years of devoted service, they die. Some readers may be startled by her rosy account of a meet and greet with a privately owned African lion, brought to her New York apartment as an apparently charming Valentine's Day surprise; it doesn't stop to contemplate, as her story "The Lady and the Tigers" does, the ethical dimensions of personal wild-animal ownership. But in general, these well-researched and readable essays—originally published in the *New Yorker* and *Smithsonian Magazine* beginning in 1995—open onto a world of troubled human relationships with charismatic beasts.

In her introduction, a piece called "Animalish"—the only newly written material in the collection—Orlean describes her lifelong interest in animalkind and speculates that she has a rare affection for it. But there's little evidence in the book of the author as an outlier. Clearly, she loves dogs, chickens, horses, and other longtime familiar companions and has gone to great lengths to make caring for many of them a focus of her wide-roaming investigative life. But the proposition that her affinity is outlandish lands with an oddly unexamined weight. *Is* a fondness for other animals strange?

Even in a culture willfully detached from the wild, animal sign is visible everywhere. I rarely enter a home, office or store that doesn't contain a simulacrum of one of them—usually several. Animal forms, references and mimicries hover all around us, even in places where no living nonhuman animals are present (at least, beyond the miniature and microscopic). They populate our language with their richness, diversity and color and play a critical role in helping us raise our children.

So when Orlean asks the question, in "Animalish," of whether her life among the other animals and her yearning for their company is atypical, I find myself wishing she'd answered the question in greater depth—wishing that, given this collection's central theme, she'd examined how humanness is constructed through and around the existence of nonhuman animals. How our notions of personhood are built on the vast foundation of our extensive evolutionary and social history with the other species that define our lived experience. In a time of pressing and accelerating biodiversity crisis, it seems more urgent than ever that we grapple with the implications of our use and abuse of other life-forms, whether domesticated or wild—with how our love for them is mediated by, and subsumed into, our exploitation of their bodies and habitats. With how and why our culture has taught us that other animals are little more than useful idiots and that, therefore, our love of them is childish, hobbyistic or weird. When in fact, our stories, homes and minds are furnished with the artifacts of a far deeper love.

The best writing in *On Animals*—about Keiko the orca, say, or about donkeys or about Biff the prizewinning boxer—occurs where the mundane meets the tragic, at the crossroads between our compulsion to care for and be near animals and our dawning realization that those animals are always, finally, beyond our sphere of nurturing and control.

Illustration by London Ladd

ESSAYS

Reveling in Nature's Eccentricities

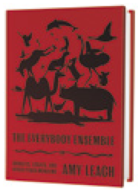
Amy Leach's latest effort—an expansive, thought-provoking reflection on the natural world—is a worthy successor to her celebrated first book, *Things That Are*. A winner of the Whiting Award and the Pushcart Prize, Leach charms even as she challenges the reader with this new collection.

In the titular essay, a choir director encourages everyone on the "Existence Boat" to raise their voices in a joyous cacophony of Being. It is an apt kickoff for a book so planetary in scope. The "Pandemoniums" that follow cover everything from the chaotic mindfulness of Beanstan, Leach's unhinged Pomeranian, to Elon Musk's recent spaceflight, the premise of which she rejects on the basis of her loyalty to Earth: "Yes to the Earth, my Earth, for I do not hope to find a better where."

But Leach's love for Earth is not unexamined. She often criticizes humanity's reductive view of animals, noting our propensity to collapse them into anatomy or taxonomy and rejecting our tendency to use them as religious symbols. (One example of the latter is "Dogness defies dogma.") Instead, Leach argues, our animal brethren's identity is inherent, and they stand for nothing but themselves.

In "Non Sequiturs," she illustrates the application of this through an animal-oriented exegesis of the Book of Job, highlighting how God "brings lions and lightning and various other non sequiturs, like donkeys" to answer Job's many questions. "Perhaps," Leach remarks, "we could try his rhetorical method ourselves." And she does just that, illuminating her essays with a dizzying array of nature references: some household names (eagles, grapes, seahorses), others less so (strawberry frogs, Gegenschein, *Flabellina*). After importing them, she does not just set them blithely down, but rather she rubs them together with her point until insights shoot like sparks. If they are non sequiturs, they still forge links via revelation rather than relatedness.

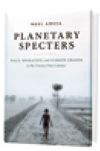
Leach's essays are passionate, but they refresh more than burn. While breathtakingly sophisticated in their content, their tone recalls the best and most beloved children's books: playful but gentle, earnest without being naive, reverberant with ontological wonder. Fusing poetry and biology, philosophy and commentary, this collection offers something for everyone on the Existence Boat. —*Dana Dunham*



The Everybody Ensemble:
Donkeys, Essays, and Other Pandemoniums
By Amy Leach.
Farrar, Straus and Giroux, 2021 ($26)

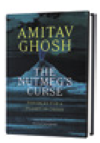
IN BRIEF

Planetary Specters:
Race, Migration, and Climate Change in the Twenty-First Century
by Neel Ahuja.
University of North Carolina Press, 2021 ($95)



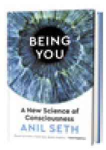
When journalists and policy makers discuss migration crises, Neel Ahuja writes, they tend to blame the amorphous boogeyman of "climate change" without interrogating the web of underlying roots. In *Planetary Specters,* he tugs at the thread—namely, oil—that connects much of the global economy to unravel how capitalist production doesn't just generate cascading conditions for warming but creates a "shrinking horizon of habitation" for the much of the world's poor. There are no easy answers, of course. But as the planet continues hurtling toward disaster at breakneck speed, Ahuja presents a convincing framework for understanding environmental racism. —*Tess Joosse*

The Nutmeg's Curse:
Parables for a Planet in Crisis
by Amitav Ghosh.
University of Chicago Press, 2021 ($25)



In this essayistic follow-up to his 2016 book *The Great Derangement: Climate Change and the Unthinkable,* Amitav Ghosh sees the seeds of our climate emergency in the violent 17th-century occupation of the nutmeg plantations of the Banda Islands in Indonesia. To Ghosh, the policies of the Dutch East India Company illustrate "the unrestrainable excess that lies hidden at the heart of the vision of world-as-resource—an excess that leads ultimately not just to genocide but an even greater violence, an impulse that can only be called 'omnicide,' the desire to destroy everything." Ghosh finds hope in the promise of renewable energy and the "vitalist politics" of Greta Thunberg, the activists of Standing Rock, and others. —*Seth Fletcher*

Being You:
A New Science of Consciousness
by Anil Seth. Dutton, 2021 ($28)



***Being You* is a logically rigorous** (verging on tedious) treatise on consciousness. An acclaimed British neuroscientist, Anil Seth handily summarizes the knowns and significantly more numerous unknowns of our current understanding about how "the inner universe of subjective experience relates to, and can be explained in terms of, biological and physical processes." He is just as likely to cite Immanuel Kant as recently published studies to support his claims about personhood and perception. But Seth's vivid descriptions of real-life experimental setups—such as an artificial neural network creating visual hallucinations of dogs in virtual reality—prove more imaginative and compelling than philosophical hypotheticals of false selves and teleportation. —*Maddie Bender*

Nikki O'Keefe *Getty Images*

Scientists: Please Speak Plainly

Jargon may work when talking to colleagues, but it alienates the public

By Naomi Oreskes

Naomi Oreskes is a professor of the history of science at Harvard University. She is author of *Why Trust Science?* (Princeton University Press, 2019) and co-author of *Discerning Experts* (University of Chicago, 2019).

With the persistence of vaccine denial, as well as many Americans still reluctant to face the facts of climate change even in the face of devastating floods and record-breaking heat, social media has been suffused with theories about why people don't trust science. In my own work, I have talked about how 40 years of partisan attacks on government have led to distrust of government science and then of science generally.

But this past year another issue has been bugging me. It's the way scientists *talk*. This is not a new concern. Many years ago science writer Susan Hassol and atmospheric scientist Richard Somerville wrote a humorous but serious piece about how the terms that climate scientists use mean one thing to them but often something very different to others. In the climate system, for example, "positive feedback" refers to amplifying feedback loops, such as the ice-albedo feedback. ("Albedo," itself a bit of jargon, basically means "reflectivity.") The loop in question develops when global warming causes Arctic ice to melt, exposing water that is darker and reflects less of the sun's warming rays, which leads to more warming, which leads to more melting … and so on. In the climate system, this positive feedback is a bad thing. But for most, it conjures reassuring images, such as receiving praise from your boss.

Hassol and Somerville call this "speaking in code." Codes, of course, are intended to be opaque to outsiders, but some scientific language is impenetrable even to many insiders. Consider the "secondary maximum contaminant level," or SMCL, used by the U.S. Environmental Protection Agency. Primary maximum contaminant levels (MCLs) are the maximum levels of contaminants allowed in drinking water, based on scientific evidence of health threats.

So what is a secondary standard? It's something established for reasons that do not affect public health—at least not directly. The EPA has recognized three distinct types of concern that can trigger an SMCL: *Aesthetic issues* that involve the appearance, odor or taste of the water; *cosmetic issues* that can affect your appearance, such as silver, which can cause argyria (a condition in which your skin turns irreversibly blue); and *technical issues* that involve damage to equipment. The agency is lumping three very different concerns under one term that communicates none of them. I don't know about you, but I wouldn't care if silver in my tap turned my water a bit blue. I *would* care if it turned *me* blue. And I would certainly care if damage to equipment led to my water carrying dangerous amounts of lead.

Examples of confusing and misleading scientific terms abound. When astronomers say "metals," they mean any element heavier than helium, which includes oxygen and nitrogen, a usage that is massively confusing not just to laypeople but also to chemists. The Big Dipper isn't a constellation to them; it is an "asterism." Computational scientists declare a model "validated" when they mean that it has been tested against a data set—not necessarily that it is valid. In AI, there is machine "intelligence," which isn't intelligence at all but something more like "machine capability." In ecology, there are "ecosystem services," which you might reasonably think refers to companies that clean up oil spills, but it is ecological jargon for all the good things that the natural world does for us. And then there's my favorite, which is especially relevant here: the theory of "communication accommodation," which means speaking so that the listener can understand.

Studies show that alien terms are, in fact, alienating; they confuse people and make them feel excluded. One study showed that even when participants were given definitions for the terms being used, jargon-laden materials made them less likely to identify with the scientific community and decreased their overall interest in the subject. In plain words: jargon turns people off.

Of course, there are words with specific technical meanings that cannot be otherwise easily expressed (look up "holobiont"), and astronomers may have a good reason for preferring the parsec (which equals 3.26 light-years) to the familiar light-year. Technical terms used in regulatory contexts may be hard to change for legal reasons. But if scientists could speak plainly, it would help us understand their claims and better appreciate their work.

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Illustration by Jay Bendt

OCTOBER

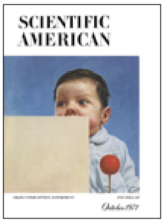
1971 Jupiter Pioneers

"Two 560-pound spacecraft are being prepared for the longest flight yet attempted: a mission to Jupiter. Pioneer F and Pioneer G will each be equipped with 11 instruments. The voyages will take between 19 and 32 months and will cover 600 million to 900 million kilometers. Each spacecraft will spend about four days in the vicinity of the solar system's largest planet. Digital data will be transmitted to the Earth at the rate of 1,024 bits per second and received by three dish antennas with a diameter of 210 feet: one in California, one in Australia and one in Spain. Power will be supplied by plutonium thermoelectric generators producing 40 watts at the start of the mission."

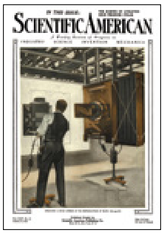
The craft, more commonly known as Pioneer 10 and 11, operated much longer than anticipated. Pioneer 10 sent signals until 2003. Today both craft are billions of kilometers from Earth, beyond our solar system.

Cable TV: 12 Channels

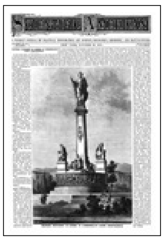
"At the beginning of 1971 there were 2,500 cable television systems serving 5.5 million subscribers in the U.S. At first it was a simple arrangement for bringing a good television signal into a home that received a poor one or none, often called 'community antenna television,' or CATV. Now cable can provide a subscriber with many more channels than there are programs to fill them. All systems built during the past three years have had at least 12 channels. The technology for carrying up to 80 black-and-white channels has been developed, but an increasing amount of reception is in color. Here the limitation resides in the receiver. Standard home television sets cannot receive more than 12 color channels without added electronic equipment."



1971



1921



1871

1921 Do Moths Use Wireless?

"How does the female moth attract males? It is not by scent, for the males travel down the wind to where the female is. Another suggestion is that the males are attracted by sound, but the female Vapourer has been enclosed in a soundproof box and still the males come to her. It has lately been suggested that moths communicate by means of 'wireless'—electromagnetic waves of exceedingly short wavelength. Probably the most sensitive organs that moths possess are their antennae. The antennae of the female, who is the transmitter, differ from those of the male, who is the receiver. This fact agrees with the design of wireless instruments. Another curious point is the behavior of the male as he nears the place where the female is stationed. Often he will alight in a very uncertain manner, moving his antennae about much the way a wireless operator will swing his direction-finding frame to discover the quarter from which the signals are coming."

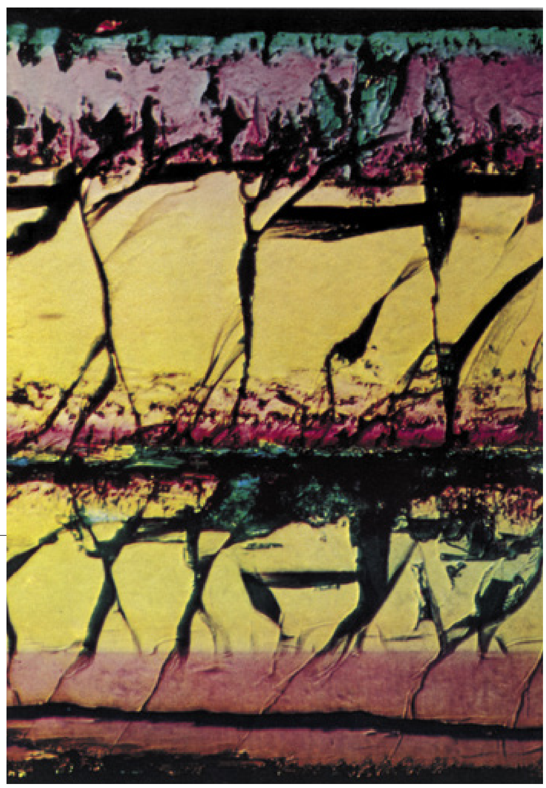
Research now indicates that male moths smell pheromones secreted by females.

1871 Tobacco Ills

"There is much to be said for and against tobacco. A habitual 'chewer' will consume four ounces per week. This is seventeen and one half pounds per year of 'hard stuff,' mingled with sand, stems, impure molasses, olive oil, chips and concentrated dirt and refuse of all kinds. A speaker at the State Dental Society said the destructive effects of tobacco upon the teeth were both mechanical and chemical. Returns from Guy's and St. Bartholomew's hospitals tell us that, in all cases of cancer of the mouth, the patient had been using a pipe. Nervousness, loss of appetite, bad dreams, vertigo, indigestion, consumption, sterility and other ills which affect the nervous system may be traced to tobacco."

Have Corpse, Will Paint

"The remains of the Italian patriot, poet and scholar, Ugo Foscolo, were exhumed at Chiswick churchyard, England, after forty-four years of interment. The body was intact, and the features were still perfect. The whiskers were still there. His skin, now of a pale gray color, remained unshrunken, the pores and textures also uninjured. With the view of making a historical painting, Signor Caldesi took a photograph of the body as it lay in its coffin, which was closed again and officially sealed."



1971: Moon rock from *Apollo 12* mission. "This [magnified] pyroxene crystal measures about two thirds of a millimeter from top to bottom. The yellow core is calcium-poor pigeonite. The pink and purple regions are calcium-rich augite. The green areas are hedenbergite, rich in iron."

Scientific American, Vol. 225, No. 4; October 1971

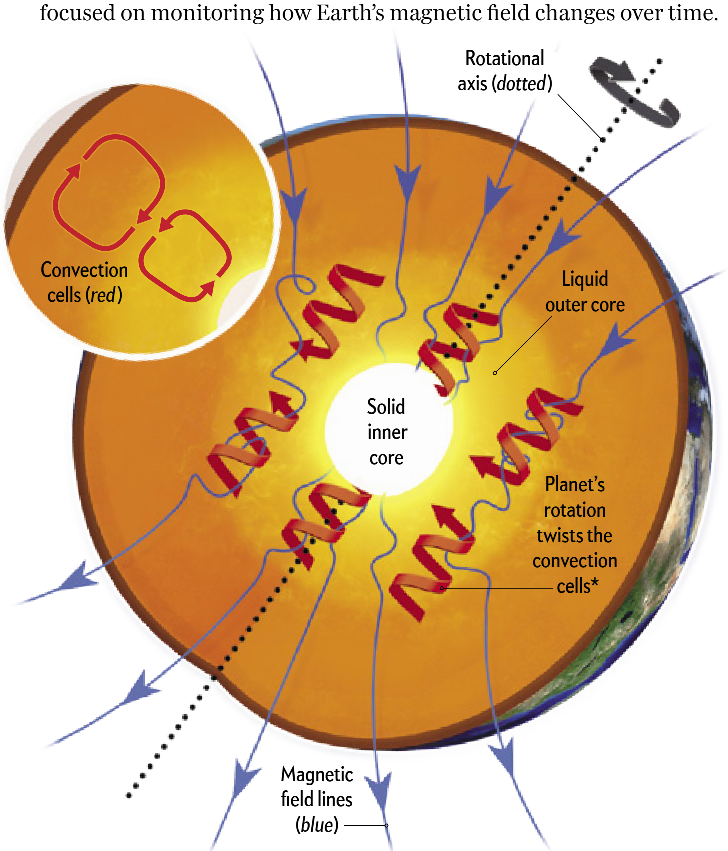
Text by Clara Moskowitz | Graphic by Mark Belan

Seeking Dynamos

Most of our neighboring planets have magnetic fields, but scientists do not fully understand how they arise

The magnetic fields in our solar system are surprisingly diverse—Jupiter's and Saturn's are extremely strong, but Mercury's is puny. Uranus's and Neptune's are out of whack with the direction of their rotation, although others are closely aligned. And each has a unique set of conditions that gives rise to a dynamo—the engine thought to activate a magnetic field.

Several upcoming space missions seek to study planetary magnetic fields, which offer a window into planets' internal makeup as well as their history and formation. NASA's Juno mission, for instance, is orbiting Jupiter with two sensor experiments to make the first global map of its magnetic field, the strongest in the solar system. And the European Space Agency has a mission in orbit now called Swarm, focused on monitoring how Earth's magnetic field changes over time.



Dynamo Basics

Dynamos form inside planets when moving electric charges give rise to magnetic fields. Earth's magnetic field, for instance, originates in its outer core, which is mostly made of molten iron. This iron, a metal, is essentially a river of electrically charged particles. These particles churn and flow because of convection—the tendency of denser material to sink and hotter, less dense stuff to rise—as well as our planet's rotation. The result is a constantly moving electric current, which produces a continuous magnetic field.

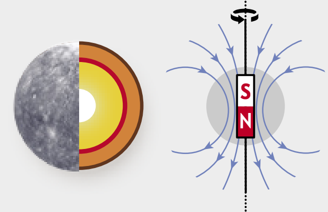
**Helices are likely smaller and more turbulent than shown here.*

Planets with Magnetic Fields

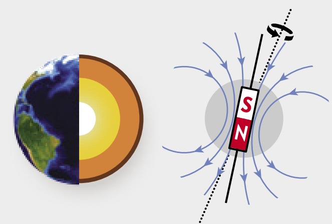
Each planet's magnetic field arises from its own unique composition and rotational properties. Venus and Mars seem to lack enough convection in their interiors to produce fields.

- Solid iron
- Liquid iron
- Iron sulfide
- Silicate mantle
- Silicate crust
- Liquid metallic hydrogen and helium
- Liquid hydrogen
- Water, methane, and ammonia
- Hydrogen and helium

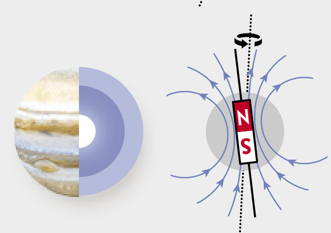
Mercury
The smallest of the planets also has the weakest magnetic field. Its internal dynamo is counteracted by the solar wind of particles streaming off the sun.



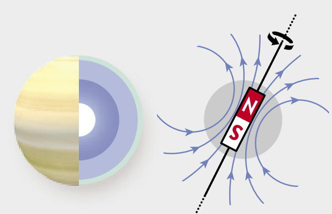
Earth
Our planet's magnetic north pole happens to point toward its geographic south pole, as do Mercury's and Uranus's.



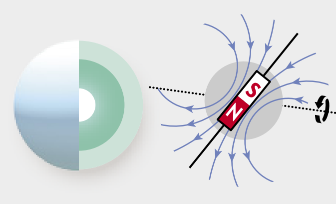
Jupiter
The solar system's strongest magnetic field is much more intense and complex than Earth's because of the gas giant's rapid rotation and larger metallic interior.



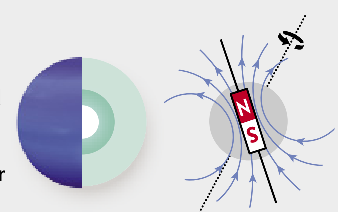
Saturn
Saturn's magnetic field is weaker than Jupiter's and symmetric around its axis of rotation, possibly because of helium rain that dampens convection in the atmosphere.



Uranus
The magnetic field here is tilted 60 degrees from the planet's rotational axis, causing the field's strength and orientation to fluctuate as Uranus spins.



Neptune
The farthest planet's magnetic axis is also misaligned from its rotational axis, giving it a lopsided shape that interacts with the solar wind in unbalanced ways.



Sources: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington (*Mercury's surface*); Reto Stöckli, NASA Earth Observatory (*Earth's surface*); NASA/JPL/Space Science Institute (*Jupiter's surface*)