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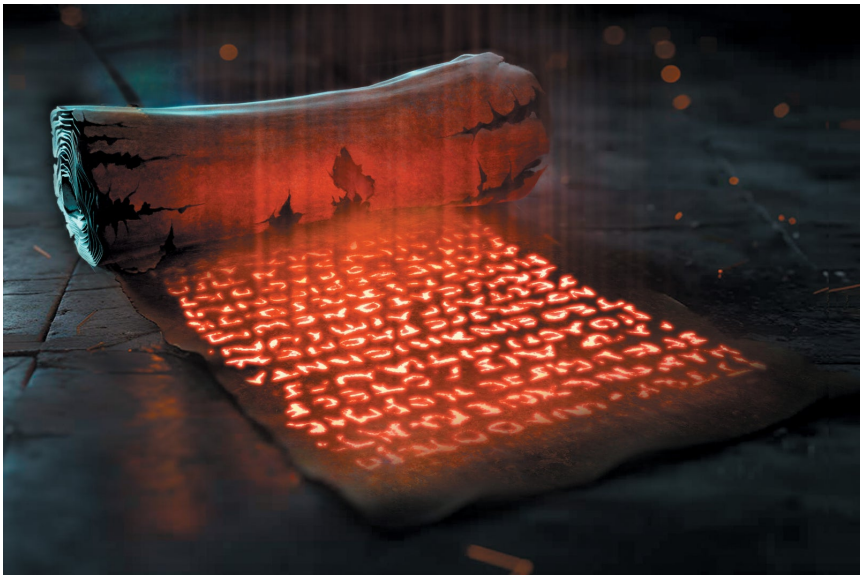
Inside the AI Competition That Decoded an Ancient Herculaneum Scroll

The Herculaneum scrolls, charred and preserved by the eruption of Mount Vesuvius, were unreadable—until now

By Tomas Weber



Kenn Brown/MondoWorks

On a warm Saturday night at the end of August last year, Luke Farritor, an undergraduate at the University of Nebraska, was sitting alone in a corner at a house party in Omaha when his iPhone pinged. The music was booming, and Farritor, 21 years old at the time with a boyish face and black rectangular glasses, was surrounded by other students drinking and mingling. He opened the message. It was from Ben Kyles, a 45-year-old computer scientist and pianist from British Columbia, known to Farritor as “Hari Seldon”—Kyles’s online avatar, named for a character in Isaac Asimov’s Foundation series. Kyles had some news to share. He had just finished digitally unrolling some high-resolution scans of carbonized papyrus. He’d uploaded the images, he said, to a shared

server. “Dude,” Farritor replied, “this is awesome. I’ll run it very soon.”

Kyles’s papyrus was from Herculaneum, an ancient Roman town on the Bay of Naples, at the base of Mount Vesuvius, that is home to the only preserved library from classical antiquity. The collection of papyri—from which about 1,800 mostly unreadable scrolls and fragments have so far been extracted—was interred under 60 feet of material deposited by pyroclastic flows, at temperatures greater than 900 degrees Fahrenheit, during the same eruption that destroyed Pompeii in C.E. 79. Without enough oxygen to burn, the scrolls were baked into charcoal—a blessing because it allowed them to join the small trove of papyri that has managed to endure since antiquity, all of it protected from humidity in some way or another, whether inhumed in Egyptian sands or singed by fire. But it also means they cannot be unrolled without turning to dust.

Using his phone, Farritor, who had been working late nights attempting to decipher the scrolls for most of the preceding six months, remotely dialed in to his desktop computer in his dorm room in Lincoln, an hour’s drive away. He located Kyles’s new papyrus segment on the server and immediately fed it into the artificial-intelligence-powered detector he had been building over the past few weeks. The detector was programmed to find ink, and therefore letters, and therefore words. He booted up the program to let it run, and he put his phone away. As the designated driver, he waited for the party to finish so he could deliver his friends back to their dorms.

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For four centuries monks and princes, papyrologists and archaeologists, classicists and computer scientists have struggled to little avail to detect any letters or words inside the scrolls—which resemble saggy little brown burritos—without destroying them in the process. If we could read them, as classicists and papyrologists have long hoped to do, we might discover lost works of classical literature or philosophy or records of history and science. Perhaps they contain tragedies by Sophocles or Aeschylus or the lost writings of Livy. “The possibilities,” says David Blank, a professor of classics at the University of California, Los Angeles, “are enormous.”

Almost all classical literature has come down to us from medieval monks, choosy in what they resolved to copy. As a result, relatively little “original” writing from antiquity exists, which means classical literature, from our point of view, is a panorama seen through a pinhole. We have seven plays by Aeschylus, but we know the tragedian wrote at least 10 times more than that. The preserved papyri in Herculaneum are our best shot at rescuing lost works, and some classicists suspect that even more texts could remain in areas of the villa yet to be excavated. “Who knows what’s there?” says Annalisa Marzano, a professor of classical archaeology at the University of Bologna and a trustee of the Friends of Herculaneum Society. In addition to works by the big hitters such as the poets Virgil and Horace, there’s also the tantalizing possibility of finding writing from authors “we know absolutely nothing about,” Marzano says.

Hundreds of papyrus scrolls in the ancient city of Herculaneum were preserved after the eruption of Mount Vesuvius. For thousands of years, no one could open them without doing irreparable damage. Credit: Courtesy of EduceLab/University of Kentucky

After dropping off his friends, Farritor parked outside his dorm and, walking toward his building, took his phone out of his pocket. He unlocked the screen. He halted. “Holy cow,” he said. The AI had outputted something.

On the phone’s screen, set against the grayscale crisscross texture of woven papyrus, were three black lowercase Greek characters arranged in clear sequence. They were fuzzy but unmistakable: pi (π), omicron (o), rho (ρ)—“$\pi o \rho$.”

The first person in almost 2,000 years to see those letters glimpsed them late on a summer night in a parking lot in Lincoln, having salvaged them from an ancient eruption. “I freaked,” he told me when we spoke last November. He sent a screenshot to his mom. It was a stunning beginning. But what, Farritor wondered, was the word containing those letters? And which lost book housed that word?

As the AI industry exploded last spring with the release of GPT-4, so did anxiety about superintelligent AI. Many “doomer” developers and thinkers in Silicon Valley and beyond warn that a system could someday choose to reduce our civilization to dust and

rubble with the force of numerous Vesuviuses. This concern makes it all the more poignant that, over the past several months, hundreds of amateur decipherers have decided to spend their time building AI in the hopes of glimpsing never before seen writings found in a city that went extinct in the wake of a terrible catastrophe. The Vesuvius Challenge is a competition to rescue the knowledge in these scrolls. For Ahron Wayne, a Michigan-based industrial CT engineer participating in the challenge, the mission, he says, is about “as close as you can get to a video game.”

None of the strongest contenders have any expertise in classics. Most have only a passing interest in, and very little knowledge of, the ancient world. Most speak no Latin, no Greek. It is the technical problem that interests them—that and the Vesuvius Challenge’s collective prize of more than $1 million, which has been donated by some of Silicon Valley’s most powerful players.

The competition was the brain wave of Nat Friedman, a 46-year-old Bay Area investor. Until 2021, Friedman was CEO of Git-Hub, Microsoft’s open-source software-development platform. Together with Daniel Gross, his longtime investment partner, he was an early financier of today’s AI windfall. In the 2010s Friedman and Gross wrote checks to machine-learning researchers, and later, when the field exploded, they started funding AI companies. Today, to train the AI models they’ve bet on, the pair possess more Nvidia AI chips than most countries. Perhaps you’ve heard that tech billionaires are planning to build a utopian city from scratch on farmland north of San Francisco; Friedman has plowed his money into that project, too. In the spring of 2020, though, with much of the world in shutdown, Friedman was hoping simply to take his mind off the plague.

High-energy scans allow scientists to virtually unwrap the scrolls into 3-D images, so that AI tools can be applied to look for invisible patterns in the ink.
Credit: Courtesy of EduceLab/University of Kentucky

Quarantined at home in San Francisco and newly fascinated by ancient Rome, Friedman was reading Wikipedia articles about ancient disasters and calamities. In 1709, he learned, workers in the town of Resina near Naples were digging a well. At around 60 feet down their spades hit the remnants of an enormous theater. The building, which seated 2,500 people, was filled with statues of horses and noblemen. They must have been stunned. The existence of Herculaneum, the ancient town underneath their feet, had long ago slipped from collective memory.

Over the next few decades a succession of military engineers, desperate for ancient artworks to decorate their own villas, gave orders to dig underground tunnels fanning out from the theater. This activity caused severe damage. Conservation-oriented archaeological methods had yet to be developed, and one Spanish military engineer, in the words of 18th-century art historian Johann Joachim Winckelmann, “knew as much of antiquities as the moon knew of lobsters.”

In 1750 Karl Weber, a Swiss engineer, discovered a lavish villa by following an underground wall. The oceanfront property probably once belonged to the father-in-law of Julius Caesar, Lucius

Calpurnius Piso Caesoninus. In a corner of the building, workers discovered a pile of black, misshapen cylinders a few inches high. The objects were initially thought to be carbonized wood, and some were thrown away—until Weber realized the room was a library. The workers removed more than 1,000 papyrus rolls and fragments, which were placed in a local museum.

The prospect of finding an unknown work of literature in the stash captivated much of Europe, and experimentalists tried various approaches to reading the papyri. A museum curator vertically sliced through a few scrolls with a knife, scraping off layers. This brutal method uncovered some legible text, but it ruined the scrolls. An Italian prince who had recently invented a waterproof cape for the future king of Spain immersed a few scrolls in mercury, hoping the liquid metal would separate the pages. It destroyed them. Others tried exposing them to a foul-smelling “vegetable gas” or slathering the rolls in rosewater.

In 1753 Antonio Piaggio, a monk who oversaw the ancient manuscripts in the Vatican Library, was summoned from Rome. Once in Naples, he invented a machine for slowly unrolling the papyrus, attaching silk threads to the edge of the sheets and gently prizing the layers apart at a rate of maybe a tenth of an inch a day. Piaggio had some success with this method and was able to reveal works by Philodemus, who taught Virgil and was one of the Greek Epicurean philosophers who held that atoms swerving and colliding in a void created the universe. But Piaggio’s approach was as destructive as it was slow. It seemed impossible to read the more than 330 still unopened scrolls without damaging them.

A few centuries later Friedman read about some recent breakthroughs. A group at the University of Kentucky, led by Brent Seales, a professor of computer science, seemed to be on the edge of success. In 2019 Seales’s team had arranged for two complete scrolls to be transported in custom-made cases, along with four broken-off fragments, to the Diamond Light Source, a synchrotron

particle accelerator in Oxfordshire, England. Using the synchrotron's high-energy photons, Seales and his team took micro-CT scans of the papyri at a resolution of eight microns, about the diameter of a red blood cell.

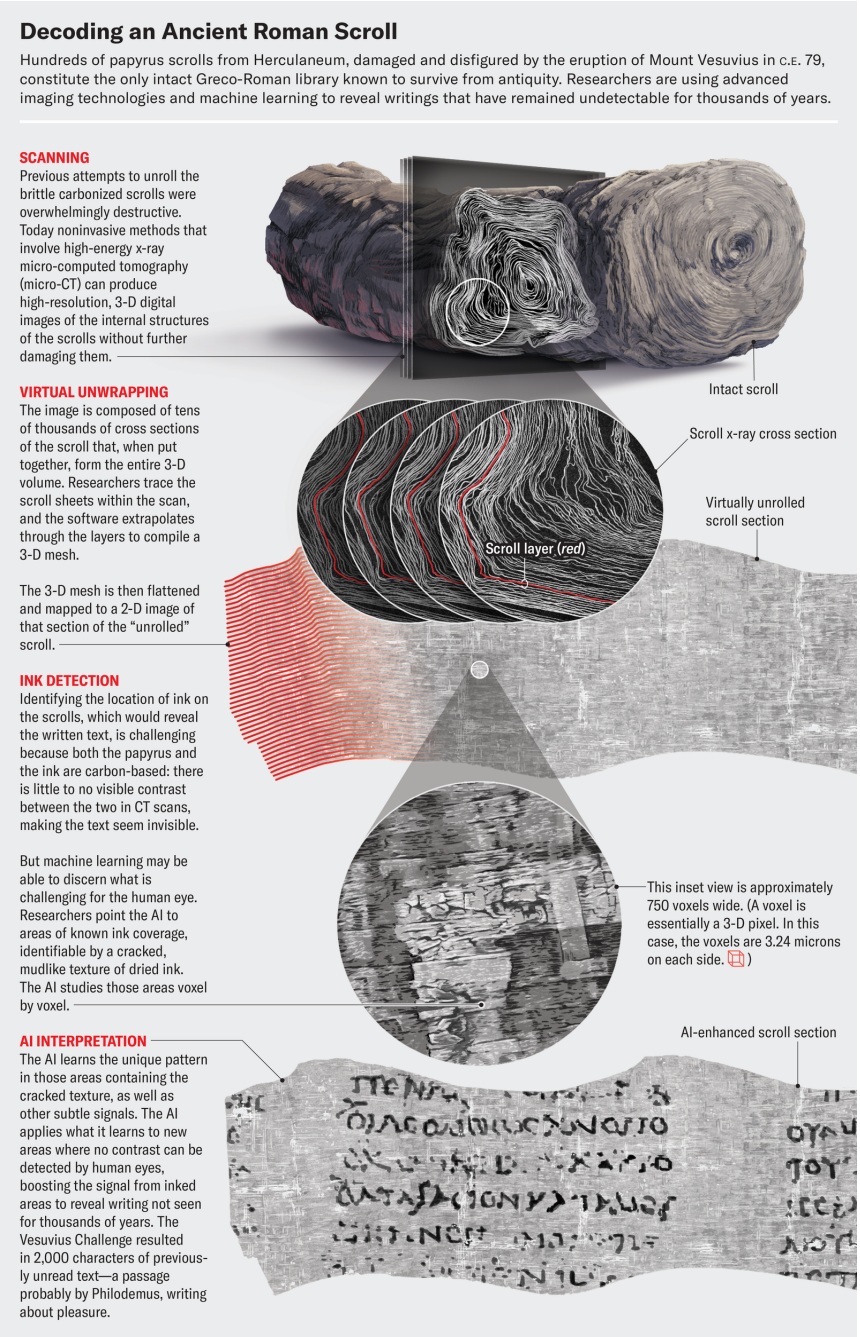
Seales's plan was to import the synchrotron scans into a custom-designed computer program to virtually unwrap each layer of papyrus, in the hopes of revealing ink on the rendered surfaces. The carbon-based ink used on the scrolls, though, had a radiodensity similar to that of the papyrus. That meant there wasn't enough contrast for the ink to show up in the scans.

To get around the problem, Seales's team built a machine-learning model trained on manuscripts written in carbon ink. A successful ink-detection AI model could perhaps then be applied to the virtually unwrapped surfaces of the scrolls.

When Friedman read about this effort, he got an idea: perhaps Silicon Valley's AI community could help, either by investing in the project or by offering its expertise. In 2022 Friedman invited Seales to Frontier Camp, an exclusive, furtive gathering (it has no online presence) that Friedman co-organizes and that takes place in the remote woods of northern California, where a handpicked elect of technologists—about 200 founders and CEOs—camp out in the cold for a few nights every year to throw ideas around.

Seales ignored the e-mail. He'd heard of Friedman but didn't believe the correspondence was real. Friedman, though, was tenacious—and in October 2022 Seales arrived at the spartan summer-camp venue in the redwood forest of Sonoma County. That night, in one of the camp's wood outbuildings, Seales gave a talk to a group of machine-learning engineers. "We're going to solve this in the next hour," Friedman whispered to Gross while Seales was still speaking. But they didn't—and when the event ended, Friedman and Gross were worried that Seales would return to Kentucky empty-handed. So that evening, over bourbon in the

bar of Seales's Palo Alto hotel, Friedman suggested they organize an open contest instead. "We'll put up some money for it," he told Seales.



Credit: Matthew Twombly; Christy Chapman/University of Kentucky and Stephen Parsons/Vesuvius Challenge (*consultants*); Amanda T. Hobbs (*background research*)

Seales flew home to discuss the idea with the other members of his laboratory. "We don't want to be stupid and just give away all this work we've done," said Stephen Parsons, a digital-restoration researcher who was finishing up a Ph.D. thesis on the lab's work.

At the same time, they had more ideas than they could reasonably try out by themselves. More people grappling with the problem would make it more likely the scrolls would be read, which was their ultimate goal. It was settled. They would open the project to the world. Friedman struggled to contain his enthusiasm. “Working on a very exciting and weird new side project,” he wrote on Twitter (now X). “Kind of a lifelong dream type thing.”

With Friedman, the group devised the competition’s structure. There would be stages of freestanding prizes for different challenges, including detecting ink, finding the first letters in the scrolls and building useful open-source software. The deadline for entries for the grand prize—for identifying four separate passages of at least 140 characters—would be December 31, 2023. “How would the ancient Romans feel,” Friedman wrote on X on the Ides of March, the day the competition launched (which was also the day after the release of GPT-4), “if they knew that 2000 years later, we would be using particle accelerators and supercomputers to read their words, preserve them for eternity, and whisper them into the ear of a baby god?”

Shortly after the competition opened, I joined the contest’s server on Discord, a message-board platform built for gamers. I was one of around 400 people who also signed up in the first few weeks, and by fall the board was bustling with 1,428 members. The competitors had downloaded the 5.5 terabytes of scan images of two scrolls, which Seales had nicknamed Banana Boy and Fat Bastard (their real names are PHerc_Paris_3 and PHerc_Paris_4), and were discussing what to do with them. For contestants who knew serious prize money was at stake, people were tossing ideas around with surprising candor.

There were two main tasks: segmentation and ink detection. To find letters, you need clean surfaces, or segments, of papyrus. Along the z axis of each scroll, from top to bottom, the researchers had taken thousands of cross-sectional x-rays. Each cross section

reveals rolled-up papyrus sheets like rings of a tree, wispy white lines spiraling against a dark background. Unwrapping the rolls and extracting a flat surface takes forever. It requires using mouse clicks to mark the changing position of a sheet in every cross section. Then, bespoke algorithms stitch the individual cross sections together into a single sheet. But this is stymied by the fact that the carbonization melded some of the sheets together. Sometimes the papyrus folds back on itself, or it becomes unstuck, with one sheet becoming several and no way of knowing which surface holds the writing.

“It’s fused, mushy chunks of coal,” says Kyles, who was hired by Friedman to segment full-time and share the results with the community. With the help of open-source software developed by other participants, Kyles and his team of nine-to-five segmenters were able to churn out about 0.2 square inch of papyrus surface per hour. (The length of a Herculaneum scroll can be more than 32 feet.)

Spotting any ink on those surfaces, though, was a different matter entirely. To boost progress in ink detection, the organizers launched a machine-learning contest on Kaggle, an online platform for data-science competitions, with prizes totaling $100,000. The task was relatively straightforward: build a machine-learning model to detect ink in the CT scans of broken-off papyrus fragments on which writing was already clearly visible (an approach the Kentucky team had already tried with some success). An ink-detection model trained on the fragments, the organizers hoped, could then be applied to segments of virtually unwrapped papyrus.

The scrolls at the center of the Vesuvius Challenge came from the only preserved library from classical antiquity. Herculaneum, an ancient Roman town on the Bay of Naples, was destroyed in the eruption of Mount Vesuvius in C.E. 79.
Credit: Bildagentur-online/Getty Images

A total of 2,763 competitors and teams—including a pair of students at China's Harbin Institute of Technology, a team of archaeologists from Kyiv, a medical-imaging research group in Germany, and machine-learning engineers in Japan and South Korea—signed up. They built AIs to predict the presence or absence of ink in each voxel (the three-dimensional equivalent of a pixel) of the scanned fragments and uploaded their results. Their entries were verified against data from infrared photographs of the fragments.

In the weeks leading up to the close of the Kaggle competition on June 14, 2023, a team in San Diego found itself toward the bottom of the leaderboard. Tinkering with their model in cafés across the city, the teammates noticed that the ink had saturated the papyrus more deeply in certain areas. Their model was learning to place importance on the ink's depth—but this approach was confusing it. The researchers tweaked the model to ignore the depth of the ink, which led to better results, propelling the group to the top of the leaderboard. The depth-invariant model went on to win the ink-detection competition. But something was wrong.

When Ryan Chesler, one of the team members, applied his winning model to a large section of Kyles's virtually unrolled papyrus, known as the Monster Segment, he was disappointed. The AI was not detecting any ink at all. A model trained on the fragments, it seemed, would not work on the full scrolls. Wayne, the CT engineer in Michigan, thought he knew why. The ink-detection prizewinners "are a bunch of freaking brainiacs," he says. But they were thinking of the conundrum as a math problem. "The real world is a little bit messier," Wayne explains. The ink-detection models might have failed to work on the scrolls because the AI was not able to learn what carbonized papyrus looked like. Without more scans of carbonized papyrus, even the most sophisticated algorithms would struggle.

More familiar with scanning objects such as rocket motors and bassoons, Wayne convinced his employer to let him use one of their state-of-the-art CT scanners in his free time. ("If someone were to win the grand prize," he says, "they could afford almost half of one of these.") He drew sophisticated Grecian profiles on papyrus, which he then carbonized and scanned. He shared the results with others, creating a rich store of training data.

Others believed the contestants were too focused on AI. Casey Handmer, an Australian physicist in his 30s, decided to visually inspect the scans instead. "If a machine can see it, a human can see it," he says. Most machine-learning algorithms for detecting visual features, Handmer explains, are built on human detection, and for good reason: our visual cortex is highly adept at identifying subtle patterns and textures.

Handmer is the founder and CEO of Terraform Industries, a California start-up that produces carbon-neutral natural gas from sun and air, with headquarters in a mock medieval castle in Burbank. He spent hours inspecting the images, to the irritation of Friedman, an investor in Terraform, who did not approve of the CEO's distraction. After a break to 3-D print a copy of his skeleton

for his own amusement, Handmer found he was becoming increasingly familiar with the visual features of the burned papyrus fibers. And in May, while inspecting Kyles's Monster Segment, he noticed something remarkable. He kept seeing a recurring texture that looked like cracked mud baked on the surface of the papyrus. After an hour or so of intense staring, he noticed an upside-down π. The cracked texture had to be ink.

Handmer found more of that texture in the shape of other letters and even believed he had discovered the word "Calliope" (*Καλλιόπη*), the name of the Muse of epic poetry. His findings, though, failed to persuade the six papyrologists who evaluated his entry in the first letters prize in June—a $40,000 contest for the first person to find 10 letters in an area of 0.6 square inch. But Handmer had discovered the first ink, for which he was awarded a prize of $10,000. By sharing his breakthrough with the community in almost real time, he prepared the way for the next big advance.

Farritor, the college student in Nebraska, was interning at SpaceX in Texas when he learned about Handmer's discovery of the cracked texture. He spent his days working on the launchpad-software team for Starship—the most powerful rocket ever made. After work, though, he was up much of the night building an AI to find more of the cracked texture. Meanwhile Youssef Nader, an Egyptian data-science student at the Free University of Berlin, was working on a system that he had adapted from a successful Kaggle competition model. Both Farritor and Nader succeeded in finding letter sequences. Nader's results were cleaner, but Farritor was faster. After finding the *πορ* the night of the August party, Farritor continued refining his model until it spat out a couple dozen fuzzy shapes surrounding the πορ that looked like they might also be Greek letters.

In September the papyrologists inspected Farritor's results. They realized Farritor's *πορ* was the beginning of the word *πορφύρας*, or *porphoras*, the ancient Greek word for "purple." The term is rare,

says Federica Nicolardi, a papyrologist at the University of Naples who helped to confirm the word. And it is likely to be from a new text.

A few weeks later the competition flew Farritor out to Kentucky for a symposium organized around the breakthrough. Afterward JP Posma, one of the organizers, handed Farritor an oversize $40,000 check, and Nader, who found the same word just a few days later, was awarded $10,000 for second place. But just as the papyrologists were arriving for the symposium, Nader executed the biggest leap forward so far: he released an image showing *πορφύρα**c**in* the context of four full columns of text—a sight papyrologists had not expected to see in their lifetimes.

In the columns there were other identifiable words, including the possible phrase *κατάμουσικήν* (*kata mousikēn*), meaning something like “relating to music”—which makes the scroll, according to Nicolardi, most likely a work of philosophy. One night during the symposium Farritor was seen hauling Diet Cokes up to his hotel room to help him stay awake to find other long passages. In Berlin, Nader wasn’t sleeping much, either. The $700,000 grand prize seemed closer than ever.

At the end of 2023, Nader teamed up with Farritor and Julian Schilliger, a robotics student in Switzerland whose software to accelerate segmentation and map the papyrus in three dimensions had won him an earlier prize. In December, having combined their approaches, the team of three produced something astounding. Building on the work each had done individually, their AI models revealed 2,000 characters in four full columns—far outstripping the Grand Prize’s criterion of four passages of 140 characters. In early February the Vesuvius Challenge awarded them the $700,000 Grand Prize.

The readable text comprises around 5 percent of the first scroll, and it is from the same text as the earlier discoveries. It is a previously

unread tract, probably by Philodemus, about pleasure. Are good things in small quantities more delightful than copious good things? Not at all, the author concludes. “As, too, in the case of food,” writes the author, “we do not right away believe things that are scarce to be absolutely more pleasant than those which are abundant.”

The fields of papyrology and classics are changed forever. Thanks in large part to a group of amateur AI builders, we now have tools for reading the unopened Herculaneum papyri. If the technological advances continue and can be rolled out to the many unopened scrolls, says Tobias Reinhardt, a classics scholar at the University of Oxford who helped to confirm the winning entries, “we could see a recovery of ancient texts at a volume not seen since the Renaissance.”

Friedman wants more—and he isn’t stopping. His goal for 2024 is to build on the winning team’s approach to read 90 percent of the four scrolls that have now been scanned using high-energy physics. If successful, this will unlock the hundreds of unopened Herculaneum scrolls. But those are only the ones we know about. He ultimately wishes to persuade the Italian authorities to allow new excavations of the villa, in the hopes of digging out even more material.

There are still a few wrinkles to be ironed out before the process can scale. Researchers will need to find a way to automate the time-consuming and expensive manual-segmentation process. Plus, hiring a particle accelerator to scan hundreds of scrolls is too expensive, and cheaper workarounds for producing high-resolution scans will have to be found.

What is most startling for papyrologists, though, is the speed at which the AI pipeline is now finding identifiable letters. Going from three letters to entire words and phrases and then columns of text, which took Farritor, Nader and Schilliger a month, usually

takes papyrologists 20 years of intense study, says Gianluca Del Mastro, Nicolardi's colleague and a professor of papyrology at the University of Campania Luigi Vanvitelli. When Del Mastro looked at Nader's columns, Friedman noticed, he had tears in his eyes.

The technology that the Vesuvius Challenge helped to develop could be adapted for deciphering other lost texts beyond the Bay of Naples, Seales says. There are plenty of enticing contenders. In 1993, 140 carbonized papyrus scrolls dating from the sixth century C.E. were discovered in a Byzantine church in Petra, Jordan. Blackened and fragile, they were considered unreadable. And tens of thousands of fragments of the Dead Sea Scrolls have never been read because so many are stuck together. They are now prime candidates for the Vesuvius Challenge's virtual-unwrapping-to-AI-ink-detection pipeline.

Ancient Egyptian mummy masks were also made of papyrus, arranged in layers coated with plaster—a material called cartonnage, essentially a kind of papier-mâché. That papyrus often contained writing, which has been difficult to decipher without destroying the plaster. Those papyri may now have an afterlife, too.

In the fourth century B.C.E. Greek historian Xenophon noted on his return from Mesopotamia that there was a bustling trade in scrolls across the Black Sea. This means there are almost certainly sunken ships on the seafloor that contain boxes of papyrus rolls, according to Richard Janko, a classics professor and papyrologist at the University of Michigan. These scrolls are probably still preserved in this sea, which has exceptionally low oxygen and salinity for a marine environment. So far AI excitement has revolved mainly around neural networks learning how to chat. Yet more compelling is how they will get silent things to speak.

Tomas Weber is a writer who lives in London. He has written for many publications, including *WIRED*, the *Financial Times Magazine* and the *Economist's 1843* magazine.

Building Intelligent Machines Helps Us Learn How Our Brain Works

Designing machines to think like humans provides insight into intelligence itself

By George Musser

Kenn Brown/MondoWorks

The dream of artificial intelligence has never been just to make a grandmaster-beating chess engine or a chatbot that tries to break up a marriage. It has been to hold a mirror to our own intelligence, that

we might understand ourselves better. Researchers seek not simply artificial intelligence but artificial general intelligence, or AGI—a system with humanlike adaptability and creativity.

Large language models have acquired more problem-solving ability than most researchers expected they ever would. But they still make silly mistakes and lack the capacity for open-ended learning: once they are trained on books, blogs, and other material, their store of knowledge is frozen. They fail what Ben Goertzel of the AI company SingularityNET calls the “robot college student test”: you can’t put them through college (or indeed even nursery school).

The one piece of AGI these systems have unequivocally solved is language. They possess what experts call formal competence: they can parse any sentence you give them, even if it’s fragmented or slangy, and respond in what might be termed Wikipedia Standard English. But they fail at the rest of thinking—everything that helps us deal with daily life. “We shouldn’t expect them to be able to think,” says neuroscientist Nancy Kanwisher of the Massachusetts Institute of Technology. “They’re language processors.” They skillfully manipulate words but have no access to reality other than through the text they have absorbed.

In a way, large language models mimic only the brain’s language abilities, without the capacity for perception, memory, navigation, social judgments, and so forth. Our gray matter performs a

bewildering mashup of overlapping functions, some widely distributed across the brain, others more localized. People who have suffered a stroke in one of their language areas may be unable to speak but may still be able to add numbers, compose symphonies, play chess and communicate by gestures as well as they could before. AI developers are incorporating such modularity into their systems in the hope of making them smarter.

OpenAI, the creator of the Generative Pre-trained Transformer (GPT), lets paid users select plug-insto handle math, Internet search, and other kinds of queries. Each plug-in calls on some external bank of knowledge pertaining to its specialty. Further, and invisibly to users, the core language system may itself be modular in some sense. OpenAI has kept the specs under wraps, but many AI researchers theorize that GPT consists of as many as 16 separate neural networks, or “experts,” that pool their answers to a query—although how they divide their labor is unclear. Last December Paris-based AI company Mistral made a big splash by releasing an open-source version of this “mixture of experts” architecture. The main advantage of this simple form of modularity is its computing efficiency: it is easier to train and run 16 smaller networks than a single big one. “Let’s get the best of both worlds,” says Edorado Ponti, an AI researcher at the University of Edinburgh. “Let’s get a system that has a high number of parameters while retaining the efficiency of a much smaller model.”

But modularity comes with trade-offs. No one is sure how brain regions work together to create a coherent self, let alone how a machine could mimic that. “How does information go from the language system to logical reasoning systems or to social reasoning systems?” wonders neuroscientist Anna Ivanova of the Georgia Institute of Technology. “That is still an open question.”

One provocative hypothesis is that consciousness is the common ground. According to this idea, known as global workspace theory (GWT), consciousness is to the brain what a staff meeting is to a

company: a place where modules can share information and ask for help. GWT is far from the only theory of consciousness out there, but it is of particular interest to AI researchers because it conjectures that consciousness is integral to high-level intelligence. To do simple or rehearsed tasks, the brain can run on autopilot, but novel or complicated ones—those beyond the scope of a single module—require us to be aware of what we're doing.

Goertzel and others have incorporated a workspace into their AI systems. "I think the core ideas of the global workspace model are going to pop up in a lot of different forms," he says. In devising electronic representations of this model, researchers are not seeking to make conscious machines; instead they are merely reproducing the hardware of a particular theory of consciousness to try to achieve a humanlike intelligence.

Could they inadvertently create a sentient being with feelings and motivations? It is conceivable, although even the inventor of GWT, Bernard Baars of the Neurosciences Institute in La Jolla, Calif., thinks it's improbable. "Conscious computing is a hypothesis without a shred of evidence," he says. But if developers do succeed in building an AGI, they could provide significant insight into the structure and process of intelligence itself.

GWT has long been a case study of how neuroscience and AI research play off each other. The idea goes back to "Pandemonium," an image-recognition system that computer scientist Oliver Selfridge proposed in the 1950s. He pictured the system's modules as demons shrieking for attention in a Miltonian vision of hell. His contemporary Allen Newell preferred the more sedate metaphor of mathematicians solving problems together by gathering around a blackboard. These ideas were taken up by cognitive psychologists. In the 1980s Baars put forward GWT as a theory of human consciousness. "I learned a great deal from AI my whole career, basically because it was the only viable theoretical platform that we had," he says.

Baars inspired computer scientist Stanley Franklin of the University of Memphis to try to build a conscious computer. Whether or not Franklin's machine was truly conscious—Baars and Franklin themselves were dubious—it at least reproduced various quirks of human psychology. For instance, when its attention was drawn from one thing to another, it missed information, so it was just as bad at multitasking as people are. Starting in the 1990s, neuroscientists Stanislas Dehaene and Jean-Pierre Changeux of the Collège de France in Paris worked out what type of neuronal wiring might implement the workspace.

In this scheme, brain modules operate mostly independently, but every tenth of a second or so they have one of their staff meetings. It is a structured shouting contest. Each module has some information to offer, and the more confident it is in that information —the more closely a stimulus matches expectations, for example— the louder it shouts. Once a module prevails, the others quiet down for a moment, and the winner places its information into a set of common variables: the workspace. Other modules may or may not find the information useful; each must judge for itself. "You get this interesting process of cooperation and competition between subagents that each have a little piece of the solution," Baars says.

Not only does the workspace let modules communicate with one another, but it provides a forum where they can collectively mull over information even when it is no longer being presented to the senses. "You can have some elements of reality—maybe a fleeting sensation and it's gone, but in your workspace it continues to reverberate," Dehaene says. This deliberative capacity is essential to solving problems that involve multiple steps or that stretch out over time. Dehaene has conducted psychology experiments in which he gave such problems to people in his laboratory, and he found they had to think them through consciously.

If the system sounds anarchist, that's the point. It does away with a boss who delegates tasks among the modules because delegating is

tough to get right. In mathematics, delegation—or allocating responsibilities among different actors to achieve optimal performance—falls into the category of so-called NP-hard problems, which can be prohibitively time-consuming to solve. In many approaches, such as the mixture-of-experts architecture thought to be used by OpenAI, a "gating" network doles out tasks, but it has to be trained along with the individual modules, and the training procedure can break down. For one thing, it suffers from what Ponti describes as a "chicken-and-egg problem": because the modules depend on the routing and the routing depends on the modules, training may go around in circles. Even when training succeeds, the routing mechanism is a black box whose workings are opaque.

In 2021 Manuel Blum and Lenore Blum, mathematicians and emeritus professors at Carnegie Mellon University, worked out the details of the battle for attention in the global workspace. They included a mechanism for ensuring that modules do not overstate their confidence in the information they are bringing in, preventing a few blowhards from taking over. The Blums, who are married, also suggested that modules can develop direct interconnections to bypass the workspace altogether. These side links would explain, for example, what happens when we learn to ride a bike or play an instrument. Once the modules collectively figure out which of them need to do what, they take the task offline. "It turns processing that goes through short-term memory into processing that's unconscious," Lenore Blum says.

Conscious attention is a scarce resource. The workspace doesn't have much room in it for information, so the winning module must be very selective in what it conveys to its fellow modules. That sounds like a design flaw. "Why would the brain have such a limit on how many things you can think about at the same time?" asks Yoshua Bengio, an AI researcher at the University of Montreal. But he thinks this constraint is a good thing: it enforces cognitive discipline. Unable to track the world in all its complexity, our

brains have to identify the simple rules that underlie it. “This bottleneck forces us to come up with an understanding of how the world works,” he says.

For Bengio, that is the crucial lesson of GWT for AI: today’s artificial neural networks are too powerful for their own good. They have billions or trillions of parameters, enough to absorb vast swaths of the Internet, but tend to get caught up in the weeds and fail to extract the larger lessons from what they are exposed to. They might do better if their vast stores of knowledge had to pass through a narrow funnel somewhat like how our conscious minds operate.

Bengio’s efforts to incorporate a consciousnesslike bottleneck into AI systems began before he started thinking about GWT as such. In the early 2010s, impressed by how our brains can selectively concentrate on one piece of information and temporarily block out everything else, Bengio and his co-workers built an analogous filter into neural networks. For example, when a language model such as GPT encounters a pronoun, it needs to find the antecedent. It does so by highlighting the nearby nouns and graying out the other parts of speech. In effect, it “pays attention” to the key words needed to make sense of the text. The pronoun might also be associated with adjectives, verbs, and so on. Different parts of a network can pay attention to different word relations at the same time.

But Bengio found that this attention mechanism posed a subtle problem. Suppose the network neglected some words completely, which it would do by assigning zero value to the computational variables corresponding to those words. Such an abrupt change would throw a wrench into the standard procedure for training networks. Known as backpropagation, the procedure involves tracing the network’s output back to the computations that produced it, so that if the output is wrong, you can figure out why. But you can’t trace back through an abrupt change.

So Bengio and others devised a “soft-attention mechanism” whereby the network is selective but not overly so. It assigns numerical weights to the various options, such as which words the pronoun might be related to. Although some words are weighted more highly than others, all remain in play; the network never makes a hard choice. “You get 80 percent of this, 20 percent of that, and because these attention weights are continuous, you can actually do [calculus] and apply backprop,” Bengio says. This soft-attention mechanism was the key innovation of the “transformer” architecture—the “T” in GPT.

In recent years Bengio has revisited this approach to create a more stringent bottleneck, which he thinks is important if networks are to achieve something approaching genuine understanding. A true global workspace must make a hard choice—it doesn’t have room to keep track of all the options. In 2021 Bengio and his colleagues designed a “generative flow” network, which periodically selects one of the available options with a probability determined by the attention weights. Instead of relying on backpropagation alone**,** he trains the network to work in either the forward or the reverse direction. That way it can go back to fix any errors even if there is an abrupt change. In various experiments, Bengio has shown that this system develops higher-level representations of input data that parallel those our own brains acquire.

Another challenge of implementing a global workspace is hyperspecialization. Like professors in different university departments, the brain’s various modules create mutually unintelligible jargons. The vision area comes up with abstractions that let it process input from the eyes. The auditory module develops representations that are suited to vibrations in the inner ear. So how do they communicate? They must find some kind of lingua franca or what Aristotle called common sense—the original meaning of that term. This need is especially pressing in the “multimodal” networks that tech companies have been introducing, which combine text with images and other forms of data.

In Dehaene and Changeux's version of GWT, the modules are linked by neurons that adjust their synapses to translate incoming data into the local vernacular. "They transform [the inputs] into their own code," Dehaene says. But the details are hazy. In fact, he hopes AI researchers who are trying to solve the analogous problem for artificial neural networks can provide some clues. "The workspace is more an idea; it's barely a theory. We're trying to make it a theory, but it's still vague—and the engineers have this remarkable talent to turn it into a working system," he says.

In 2021 Ryota Kanai, a neuroscientist and founder of the Tokyo-based AI company Araya, and another neuroscientist who has crossed over into AI, Rufin VanRullen of the University of Toulouse in France, suggested a way for artificial neural networks to perform the translation. They took their inspiration from language-translation systems such as Google Translate. These systems are one of the most impressive achievements of AI so far. They can do their job without being told, for example, that "love" in English means the same thing as "*amour*" in French. Rather they learn each language in isolation and then, through their mastery, deduce which word plays the same role in French that "love" does in English.

Suppose you train two neural networks on English and French. Each gleans the structure of its respective language, developing an internal representation known as a latent space. Essentially, it is a word cloud: a map of all the associations that words have in that language, built by placing similar words near one another and unrelated words farther apart. The cloud has a distinctive shape. In fact, it is the same shape for both languages because, for their all their differences, they ultimately refer to the same world. All you need to do is rotate the English and French word clouds until they align. You will find that "love" lines up with "*amour*." "Without having a dictionary, by looking at the constellation of all the words embedded in the latent spaces for each language, you only have to find the right rotation to align all the dots," Kanai says.

Because the procedure can be applied to whole passages as well as single words, it can handle subtle shades of meaning and words that have no direct counterpart in the other language. A version of this method can translate between unrelated languages such as English and Chinese. It might even work on animal communication.

VanRullen and Kanai have argued that this procedure can translate not just among languages but also among different senses and modes of description. “You could create such a system by training an image-processing system and language-processing system independently, and then actually you can combine them together by aligning their latent spaces,” Kanai says. As with language, translation is possible because the systems are basically referring to the same world. This insight is just what Dehaene was hoping for: an example of how AI research may provide insight into the workings of the brain. “Neuroscientists never have thought about this possibility of aligning latent spaces,” Kanai says.

To see how these principles are being put into practice, Kanai—working with Arthur Juliani, now at Microsoft, and Shuntaro Sasai of Araya—studied the Perceiver model that Google DeepMind released in 2021. It was designed to fuse text, images, audio, and other data into a single common latent space; in 2022 Google incorporated it into a system that automatically writes descriptions for YouTube Shorts. The Araya team ran a series of experiments to probe Perceiver’s workings and found that, though not deliberately designed to be a global workspace, it had the hallmarks of one: independent modules, a process for selecting among them and working memory—the workspace itself.

One particularly interesting implementation of workspacelike ideas is *AI People*, a forthcoming Sims-like game created by Prague-based AI company Good-AI. The version I saw last summer was set in a prison yard filled with convicts, corrupt guards and earnest psychiatrists, but the company also plans more peaceful scenarios.

The game uses GPT as the characters' brains. It controls not just their dialogue but also their behavior and emotions so that they have some psychological depth; the system tracks whether a character is angry, sad or anxious and selects its actions accordingly. The developers added other modules—including a global workspace in the form of short-term memory—to give the characters a consistent psychology and let them take actions within the game environment. "The goal here is to use the large language model as an engine, because it's quite good, but then build long-term memory and some kind of cognitive architecture around it," says GoodAI founder Marek Rosa.

A potentially groundbreaking advance in AI comes from researcher Yann LeCun of Meta. Although he does not directly cite the global workspace as inspiration, he has come by his own path to many of the same ideas while challenging the present hegemony of generative models—the "G" in GPT. "I'm advocating against a number of things that unfortunately are extremely popular at the moment in the AI/machine-learning community," LeCun says. "I'm telling people: abandon generative models."

Generative neural networks are so named because they generate new text and images based on what they have been exposed to. To do that, they have to be fastidious about detail: they must know how to spell each word in a sentence and place each pixel in an image. But intelligence is, if anything, the selective neglect of detail. So LeCun advocates that researchers go back to the now unfashionable technology of "discriminative" neural networks, such as those used in image recognition, so called because they can perceive differences among inputs—pictures of a dog versus a cat, for example. Such a network does not construct its own image but merely processes an existing image to assign a label.

LeCun developed a special training regimen to make the discriminative network extract the essential features of text, images, and other data. It may not be able to autocomplete a

sentence, but it creates abstract representations that, LeCun hopes, are analogous to those in our own heads. For instance, if you feed in a video of a car driving down the road, the representation should capture its make, model, color, position and velocity while omitting bumps in the asphalt surface, ripples on puddles, glints off blades of roadside grass—anything that our brains would neglect as unimportant unless we were specifically watching for it. “All of those irrelevant details are eliminated,” he says.

Those streamlined representations are not useful on their own, but they enable a range of cognitive functions that will be essential to AGI. LeCun embeds the discriminative network in a larger system, making it one module of a brainlike architecture that includes key features of GWT, such as a short-term memory and a “configurator” to coordinate the modules and determine the workflow. For instance, the system can plan. “I was very much inspired by very basic things that are known about psychology,” LeCun says. Just as the human brain can run thought experiments, imagining how someone would feel in different situations, the configurator will run the discriminative network multiple times, going down a list of hypothetical actions to find the one that will achieve the desired outcome.

LeCun says he generally prefers to avoid drawing conclusions about consciousness, but he offers what he calls a “folk theory” that consciousness is the working of the configurator, which plays roughly the role in his model that the workspace does in Baars’s theory.

If researchers succeeded in building a true global workspace into AI systems, would that make them conscious? Dehaene thinks it would, at least if combined with a capacity for self-monitoring. But Baars is skeptical, in part because he is still not entirely convinced by his own theory. “I’m constantly doubting whether GWT is really all that good,” he says. To his mind, consciousness is a biological function that is specific to our makeup as living beings. Franklin

expressed a similar skepticism when I interviewed him several years ago. (He passed away last year.) He argued that the global workspace is evolution's answer to the body's needs. Through consciousness, the brain learns from experience and solves the complex problems of survival quickly. Those capacities, he suggested, aren't relevant to the kinds of problems that AI is typically applied to. "You have to have an autonomous agent with a real mind and a control structure for it," he told me. "That agent has got to have kind of a life—it doesn't mean it can't be a robot, but it's got to have had some sort of development. It's not going to come into the world full-blown."

Anil Seth, a neuroscientist at the University of Sussex in England, agrees with these sentiments. "Consciousness is not a matter of being smart," he says. "It's equally a matter of being alive. However smart they are, general-purpose AIs, if they're not alive, are unlikely to be conscious."

Rather than endorsing GWT, Seth subscribes to a theory of consciousness known as predictive processing, by which a conscious being seeks to predict what will happen to it so it can be ready. "Understanding conscious selfhood starts from understanding predictive models of the control of the body," he says. Seth has also studied integrated information theory, which associates consciousness not with the brain's function but with its complex networked structure. By this theory, consciousness is not integral to intelligence but might have arisen for reasons of biological efficiency.

AI is an ideas-rich field at the moment, and engineers have plenty of leads to follow up already without having to import more from neuroscience. "They're killing it," notes neuroscientist Nikolaus Kriegeskorte of Columbia University. But the brain is still an existence proof for generalized intelligence and, for now, the best model that AI researchers have. "The human brain has certain

tricks up its sleeve that engineering hasn’t conquered yet,” Kriegeskorte says.

The quest for AGI over the past several decades has taught us much about our own intelligence. We now realize that tasks we find easy, such as visual recognition, are computationally demanding, and the things we find hard, such as math and chess, are really the easy ones. We also realize that brains need very little inborn knowledge; they learn by experience almost everything they need to know. And now, through the importance of modularity, we are confirming the old wisdom that there isn’t any one thing called intelligence. It is a toolbox of abilities—from juggling abstractions to navigating social complexities to being attuned to sights and sounds. As Goertzel notes, by mixing and matching these diverse skills, our brains can triumph in realms we’ve never encountered before. We create novel genres of music and solve scientific puzzles that earlier generations couldn’t even formulate. We step into the unknown—and one day our artificial cousins may take that step with us.

Editor’s Note (3/20/24): This article was edited after posting to correct the affiliations of Nancy Kanwisher and Anna Ivanova.

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God Chatbots Offer Spiritual Insights on Demand. What Could Go Wrong?

Large language models trained on religious texts claim to offer spiritual insights on demand. What could go wrong?

By Webb Wright

Kenn Brown/MondoWorks

Just before midnight on the first day of Ramadan last year, Raihan Khan—a 20-year-old Muslim student living in Kolkata—announced in a LinkedIn post that he had launched QuranGPT, an

artificial-intelligence-powered chatbot he had designed to answer questions and provide advice based on Islam's holiest text. Then he went to sleep. He awoke seven hours later to find it had crashed because of an overflow of traffic. A lot of the comments were positive, but others were not. Some were flat-out threatening.

Khan felt pressure at first to take the chatbot offline, but he ultimately changed his mind. He believes AI can serve as a kind of bridge that connects people with answers to their most profound spiritual questions. "There are people who want to get close to their religion [but] are not willing to spend the time to get to know more about it," Khan says. "What if I could make it all easily accessible through one prompt?"

QuranGPT—which has now been used by about 230,000 people around the world—is just one of a litany of chatbots trained on religious texts that have recently appeared online. There's Bible.Ai, Gita GPT, Buddhabot, Apostle Paul AI, a chatbot trained to imitate 16th-century German theologian Martin Luther, another trained on the works of Confucius, and yet another designed to imitate the Delphic oracle. For millennia adherents of various faiths have spent long hours—or entire lifetimes—studying scripture to glean insights into the deepest mysteries of human existence, say, the fate of the soul after death.

The creators of these chatbots don’t necessarily believe large language models (LLMs) will put these age-old theological enigmas to rest. But they do think that with their ability to identify subtle linguistic patterns within vast quantities of text and provide responses to user prompts in humanlike language (a feature called natural-language processing, or NLP), the bots can theoretically synthesize spiritual insights in a matter of seconds, saving users both time and energy. It’s divine wisdom on demand.

Many professional theologians, however, have serious concerns about blending LLMs with religion. Ilia Delio, chair of theology at Villanova University and author of several books about the overlap between religion and science, believes these chatbots—which she describes disparagingly as “shortcuts to God”—undermine the spiritual benefits that have traditionally been achieved through long periods of direct engagement with religious texts. And some secular AI experts think the use of LLMs to interpret scripture is based on a fundamental and potentially dangerous misunderstanding of the technology. Yet religious communities are embracing many types and uses of AI.

One such emerging use case is biblical translation. Before now this work was painstakingly slow; translating ancient sources into the English King James Bible, first published in 1611, took seven years and a host of devoted scholars. But LLMs are expediting the process, enabling scholars to expand the Bible’s reach. A platform called Paratext, for example, uses NLP to translate esoteric terms from scripture—such as “atonement” or “sanctification”—to produce what it describes on its website as “faithful translations of the scriptures.” And last year computer scientists at the University of Southern California launched the Greek Room, a project that aids translation of the Bible into “low-resource” languages (that is, languages for which few, if any, written records exist) through the use of an AI chatbot interface.

LLMs are also being used as a means of studying linguistic variations among translations of the Bible. In a research paper uploaded to the preprint site arXiv.com earlier this year, an international team of scientists described the use of sentiment analysis—an NLP-enabled process for detecting emotional valence in text—to analyze Jesus' Sermon on the Mount, one of the most well-known passages from the New Testament. ("Blessed are the meek, for they will inherit the earth ...") After analyzing five different translations of this sermon, including the King James version, the researchers "found that the vocabulary of the respective translations is significantly different" in each case. They also "detected different levels of humor, optimism and empathy in the respective chapters that were used by Jesus to deliver his message."

AI could help to reinvigorate theology or religious study. Computer scientist Mark Graves believes that LLMs could hypothetically be used to chip away at rigid religious orthodoxy. "In a certain sense, there's not much that's been new in theology for, like, 800 years," says Graves, who is the director of the nonprofit AI and Faith, which wrestles with the ethical challenges of AI. "Generative AI can help with that transition of breaking out of the box ... and creating new ideas."

For instance, Graves says, imagine one chatbot that's been trained on the works of Saint Augustine (C.E. 354–430) and another that's been trained on the works of Thomas Aquinas (circa 1225–1274). Theologians could then have these two noncontemporaries "speak" to each other, possibly leading to fruitful questions about, say, the nature of evil. He compares the stochastic mechanisms behind LLMs to "a novice student or even a young child [asking] a question that prompts a new way of thinking about something."

Other AI experts, however, are decidedly wary. "There's going to be a temptation to make money, to make notoriety and to gain attention by ascribing some type of revelatory quality to these

chatbots," says Thomas Arnold, a visiting scholar of technology ethics at Tufts University, who also has a doctorate in religious studies from Harvard University.

Chatbots trained on religious texts "are going to carry some of the same defects that all large language models have at the moment, the biggest of which is hallucinations," says Noreen Herzfeld, a professor of theology and computer science at Saint John's University in Minnesota. "They're going to make stuff up. And if people then believe that what these models are spouting is actually in the Quran or in the New Testament, they could be severely misled."

Max Marion, a machine-learning engineer who works on fine-tuning the performance of LLMs at AI company MosaicML, worries that Hollywood has already instilled into the public imagination an erroneous picture of AI as infallibly truthful (think of HAL 9000 from Stanley Kubrick's *2001: A Space Odyssey*, for example). But LLMs, he explains, are designed to arrange words in the most statistically logical order; what we call truth doesn't factor into the equation.

"A chatbot is just a correlation machine," says Beth Singler, an anthropologist specializing in AI and an assistant professor of digital religions at the University of Zurich. "It takes the corpus [of text], remixes the words and puts them next to each other in terms of their probability of what word follows the next.... That's not the same as understanding and explaining a doctrine."

The danger of hallucination in this context is compounded by the fact that religiously oriented chatbots are likely to attract acutely sensitive questions—questions one might feel too embarrassed or ashamed to ask a priest, an imam, a rabbi or even a close friend. During a software update to QuranGPT last year, Khan had a brief glimpse into user prompts, which are usually invisible to him. He recalls seeing that one person had asked, "I caught my wife

cheating on me—how should I respond?” Another, more troublingly, had asked, “Can I beat my wife?”

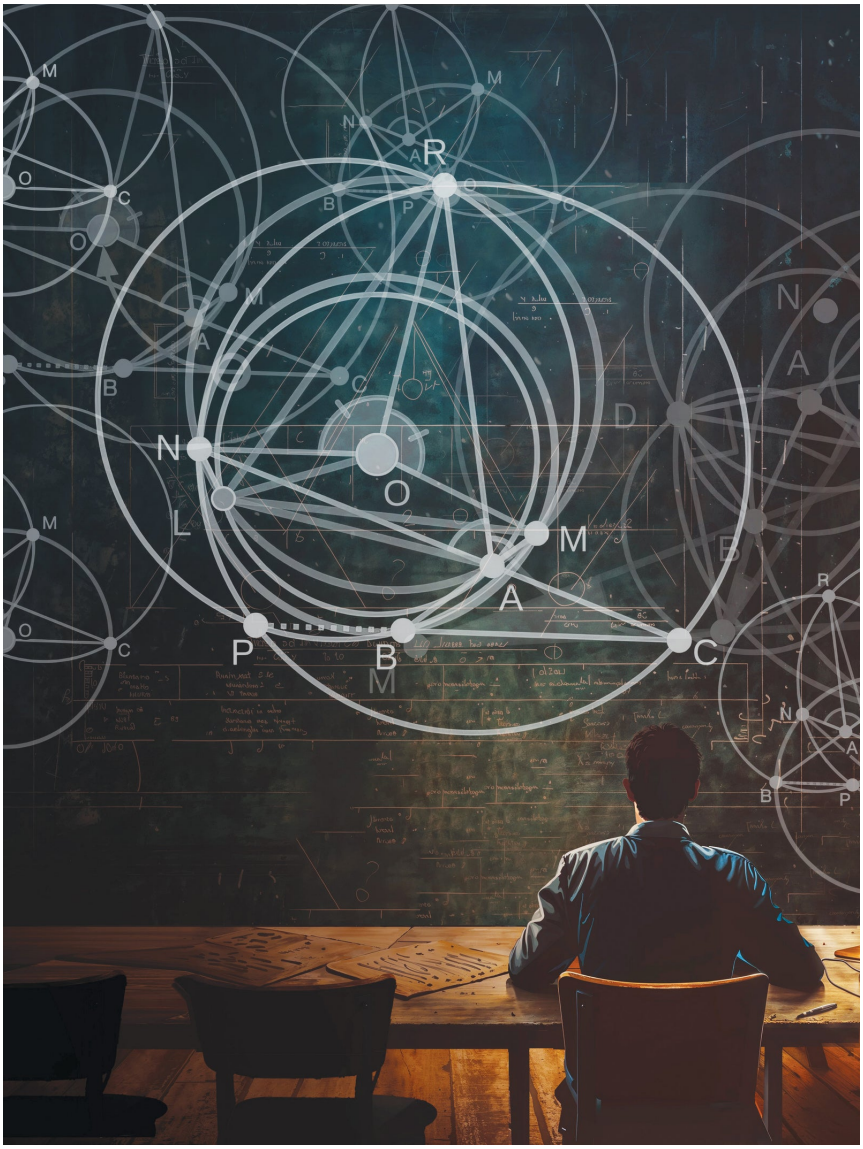
Khan was pleased with the system’s responses (it urged discussion and nonviolence on both counts), but the experience underscored the ethical gravity behind his undertaking. Indeed, other chatbots have responded with deplorable advice. There have been documented cases of Gita GPT condoning murder while citing passages from the Bhagavad Gita. Killing someone, it says, is okay as long as it’s done for the sake of protecting one’s dharma, or duty. For anyone prompting these chatbots for advice, Singler urges people to use a “hermeneutic of suspicion”—a sense of caution born from the fact that words can always be interpreted in many ways, not only by fallible human beings but now also by fallible machines.

Webb Wright is a freelance science journalist who lives in Brooklyn, N.Y.

AI Does Math as Well as Math Olympians

Until now computers have failed to solve mathematical problems. But the AI program AlphaGeometry has succeeded in finding proofs for dozens of theorems from the International Mathematical Olympiad

By Manon Bischoff



Kenn Brown/MondoWorks

The International Mathematical Olympiad (IMO) is probably the most prestigious competition for preuniversity students. Every year

students from around the world compete for its coveted bronze, silver and gold medals. Soon artificial-intelligence programs could be competing with them, too.

In January a team led by Trieu H. Trinh of Google DeepMind and New York University unveiled a new AI program called AlphaGeometry in the journal *Nature*. The researchers reported that the program was able to solve 25 out of 30 geometry problems from past IMOs—a success rate similar to that of human gold medalists. The AI also found a more general solution to a problem from the 2004 IMO that had escaped the attention of experts.

Over two days students competing in the IMO must solve six problems from different mathematical domains. Some of the problems are so complicated that even experts cannot solve them. They usually have short, elegant solutions but require a lot of creativity, which makes them particularly interesting to AI researchers.

Translating a mathematical proof into a programming language that computers know is a difficult task. There are formal programming languages specifically developed for geometry, but they make little use of methods from other areas of mathematics—so if a proof requires an intermediate step that involves, say, complex numbers, programming languages specialized for geometry cannot be used.

To solve this problem, Trinh and his colleagues created a data set that doesn't require the translation of human-generated proofs into a formal language. They first had an algorithm generate a set of geometric "premises," or starting points: for example, a triangle with some of its measurements drawn in and additional points marked along its sides. The researchers then used a deductive algorithm to infer further properties of the triangle, such as which angles matched and which lines were perpendicular to each other. By combining the premises with the derived properties, the researchers created a training data set consisting of theorems and corresponding proofs. For example, a problem could involve proving a certain characteristic of a triangle—say, that two of its angles were equal. The corresponding solution would then consist of the steps that led the deductive algorithm to it.

To solve problems at the level of an IMO, however, AlphaGeometry needed to go further. "The key missing piece is generating new proof terms," Trinh and his team wrote in their paper. For example, to prove something about a triangle, you might need to introduce new points and lines that weren't mentioned in the problem—and that is something large language models (LLMs) are well suited to do.

LLMs generate text by calculating the probability of one word following another. Trinh and his team were able to use their database to train AlphaGeometry on theorems and proofs in a similar way. An LLM does not learn the deductive steps involved in solving a problem; that work is still done by other specialized algorithms.Instead the AI model concentrates on finding points, lines, and other useful auxiliary objects.

When AlphaGeometry is given a problem, a deductive algorithm first derives a list of statements about it. If the statement to be proved is not included in that list, the AI gets involved. It might decide to add a fourth point X to a triangle ABC, for example, so that *ABCX* represents a parallelogram—something that the program

learned to do from previous training. In doing so, the AI gives the deductive algorithm new information to work with. This process can be repeated until the AI and the deductive program reach the desired conclusion. “The method sounds plausible and in some ways similar to the training of participants in the International Mathematical Olympiad,” says Fields Medalist Peter Scholze, who has won the gold medal at the IMO three times.

To test AlphaGeometry, the scientists selected 30 geometric problems that have appeared in the IMO since 2000. The program previously used to solve geometric problems, called Wu’s algorithm, managed to solve only 10 correctly, and GPT-4 failed on all of them, but AlphaGeometry solved 25. According to the researchers, the AI outperformed most IMO participants, who solved an average of 15.2 out of 30 problems. (Gold-medal winners solved an average of 25.9 problems correctly.)

When the researchers looked through the AI-generated proofs, they noticed that in the process of solving one problem, the program hadn’t used all the information provided—meaning that AlphaGeometry set out on its own and found a solution to a related but more general theorem. It was also apparent that complicated tasks—those in which IMO participants performed poorly—generally required longer proofs from the AI. The machine, it seems, struggles with the same challenges as humans.

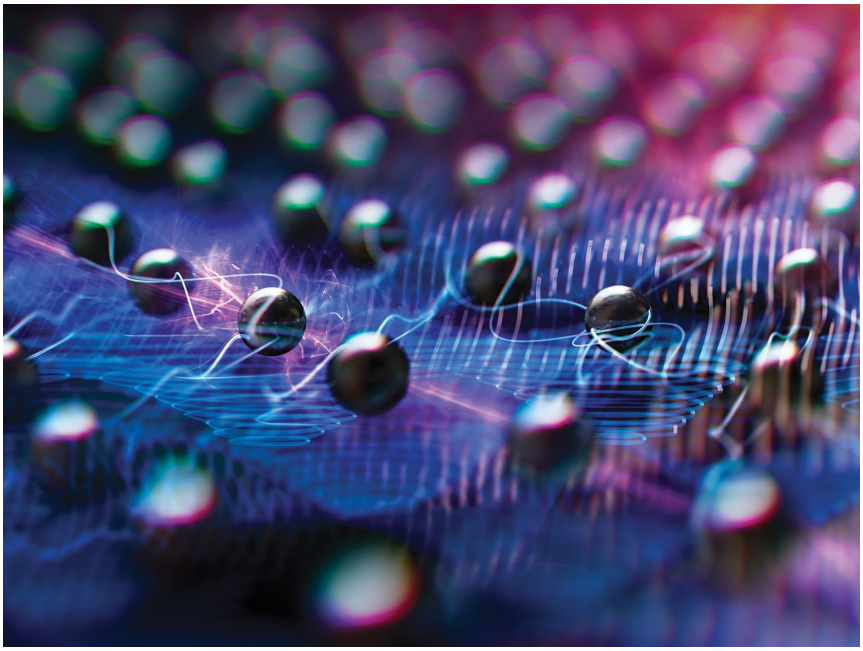
AlphaGeometry can’t yet take part in the IMO, because geometry is only one third of the competition, but Trinh and his colleagues have emphasized that their approach could be applied to other mathematical subdisciplines, such as combinatorics. Who knows—maybe in a few years a nonhuman participant will take part in the IMO for the first time. Maybe it will even win gold.

Manon Bischoff is a theoretical physicist and editor at *Spektrum*, a partner publication of *Scientific American*.

Quantum Weirdness in New Materials Bends the Rules of Physics

Electrons swarm in a soup of quantum entanglement in a new class of materials called strange metals

By Douglas Natelson



Mark Ross

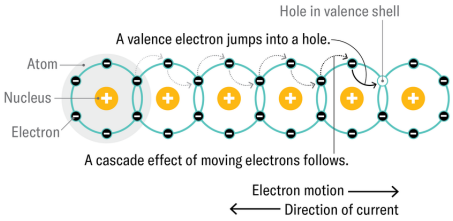
Copper, platinum, aluminum, gold. Metals have been so important in human history that we've named historical epochs (the Bronze Age, the Iron Age) for their transformative power. These materials, with their characteristic ability to conduct electricity, are no less vital to our modern era—they are found in essentially every technology that has enabled the information age. Yet despite metals' utility, scientists are still trying to decipher their inner workings.

After centuries of study, physicists have a good understanding of most metals. Their characteristic glossiness and coldness to the touch are both consequences of the way their electrons move and

interact. A metal’s reflective sheen, for instance, comes from its ability to conduct electricity at even the extremely high frequencies of visible light, and it feels cool to the touch as a result of how well it conducts heat compared with an insulating material such as wood or glass.

Recently, though, scientists have discovered that some metals are different. A new class of materials called strange metals shows confusing electronic behavior. In these metals, electrons seem to lose their individual identities, acting more like a soup in which all the particles are connected through quantum entanglement. The physics of these strongly interacting electrons even seems to mirror some of the ways particles act at the event horizons of black holes. By learning about these weird outliers, physicists hope to gain a better understanding of all metals and of the extremes of physics that are possible within solid materials.

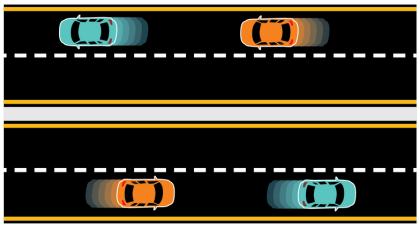
To see why strange metals are strange, let’s first consider how regular metals work. Like all physical materials, metals are made of atoms: positively charged nuclei surrounded by negatively charged electrons. Materials are held together by chemical bonds, through which atoms transfer and share electrons. In metals, some of those electrons (“valence” electrons) can move easily across many atoms, flowing freely throughout the material and carrying their negative electric charge with them when propelled by an electric field. This movement is called an electric current.



Credit: Jen Christiansen

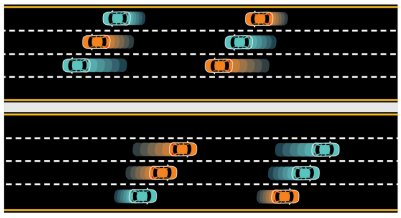
Electrons were discovered in 1897, right around the time when physicists were beginning to define the statistical properties of large numbers of particles. Given that a cubic centimeter of a solid contains something like 10^{22} atoms, any approach to describing real materials needs to be statistical. Early attempts to apply physics to the workings of solid materials assumed electrons in metal behaved like molecules in a gas. By the late 1920s, however, the first quantum revolution had taken place, revealing that electrons, like all quantum particles, have wavelike properties.

By thinking of electrons as waves, we can imagine a quantum toy model of a metal. Each electron wave has a momentum that is inversely proportional to its wavelength and a kinetic energy proportional to the square of its momentum. If we consider just one dimension, we can think of these states as traffic lanes on a highway. The lowest-energy state is the slow lane, and there is an eastbound and a westbound slow lane. A quantum law known as the Pauli exclusion principle, which states that no two electrons can share identical quantum states, implies that each lane can hold two electrons (cars), with one electron taking a value of “spin-up” and the other “spin-down.” (The quantum property of spin represents the electron’s angular momentum but isn’t equivalent to anything actually spinning.)



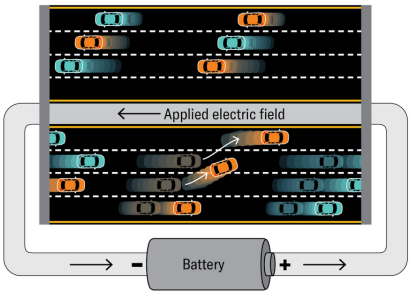
Credit: Jen Christiansen

Once the slow lanes are full, additional electron cars must go into higher-speed lanes. Now imagine many, many electron cars and therefore many, many lanes. The electrons in the slowest-moving lanes are unable to change lanes because the lanes with immediately higher or lower energy are already full (this is called Pauli blocking). Only the highest-speed electrons have access to unoccupied lanes.



Credit: Jen Christiansen

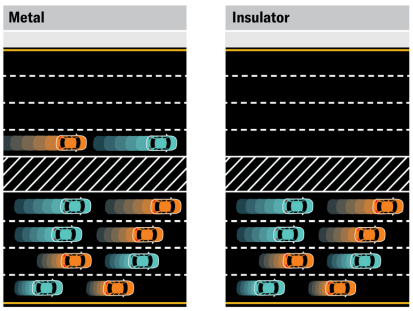
Now hook up a battery to the system to add an electric field pointing west along the highway. This field accelerates the eastbound electron cars so that the electrons with open lanes next to them can shift up to the higher-speed lanes. It also decelerates the westbound cars, causing the electrons with open slots near them to move into lower-speed westbound lanes. The resulting net increase in eastbound traffic (negative charges moving east) corresponds to an electrical current moving west.



Credit: Jen Christiansen

I call this model a toy because it deliberately ignores two important things. First, it describes only the electrons and doesn’t have anything to say about the actual atoms that make up the material. But an amazing thing happens in crystalline solids, in which the atoms line up in regular, repeating lattices. The state of each

electron looks like a wave that already takes into account the lattice. Our analogy of car lanes still applies, but now there are bands of lanes (energies) with gaps between them. If the highest-energy occupied lane has empty adjacent lanes, then the system is a metal because lane changes are still possible. In other words, the material can conduct current. If all the lanes in each band are completely full or completely empty, the system is either an insulator or a semiconductor. If it's an insulator, the energy gap between bands is very large compared with the thermal energy scale (a diamond, for example). If it's a semiconductor, the energy gap between bands is smaller (such as silicon).



Credit: Jen Christiansen

The second reason this model is a toy is that it ignores interactions between electrons, even though we learn in elementary school that like charges repel each other. The Pauli principle is key to why we can get away with this. In atoms, as this law forces additional electrons to go into higher- and higher-energy states (also called orbitals), the kinetic energy often ends up being more important than the electron-electron repulsion.

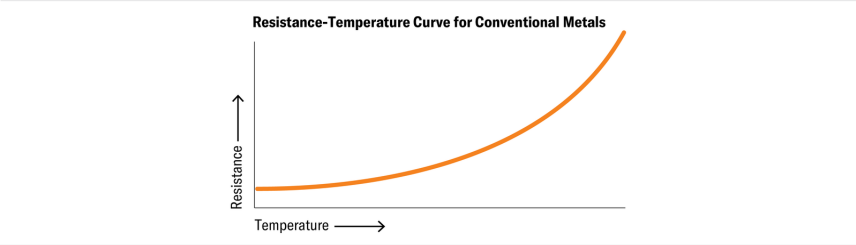
Almost 70 years ago Russian physicist Lev Landau and his collaborators introduced an incredibly successful conjecture, now known as Landau Fermi liquid theory, to try to understand electron interactions within metals.

The interacting electrons in a Fermi liquid give rise to what we call quasiparticles. A quasiparticle is an excited state that has all the properties we'd associate with a particle (charge, spin, momentum,

energy) except that it exists only when embedded in a larger, many-body system. An analogue of a quasiparticle is the “wave” cheer in a sports stadium. When fans do the wave, an observer can clearly see a pulse of standing people that seems to move around the stadium, at any time having a clear position and speed. The wave is a collective object built out of the coordinated motions of the interacting audience members, and it doesn’t even make sense to talk about the wave when there are only scattered fans—it needs a crowd. Physicists have discovered an entire zoo of quasiparticles in solid materials with names such as phonons, magnons, spinons, holons and plasmons.

Quasiparticles are the result of electron-electron interactions. An analogy would be a person trying to make their way through a crowded room—their speed, for example, is not what it would be in an empty room (the noninteracting case), because their motion is affected by the other people, who have to rearrange themselves for the person walking to get through.

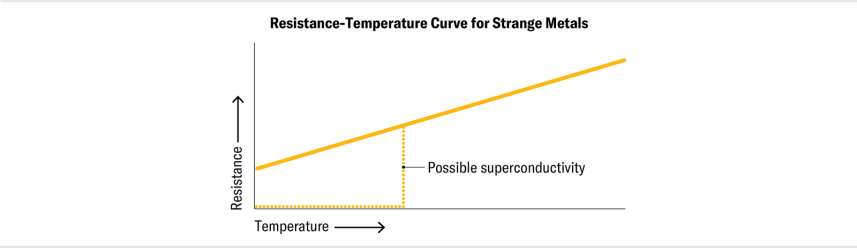
By thinking of the collective actions of electrons as quasiparticles, physicists have made testable predictions that have been verified time and again in experiments on metals such as gold, silver, copper and aluminum. For example, the electrical resistivity—how much a material resists the flow of a current through it—of a Fermi liquid at low temperatures is predicted to vary in proportion to the square of the temperature, and experiments show that it does.



Credit: Jen Christiansen

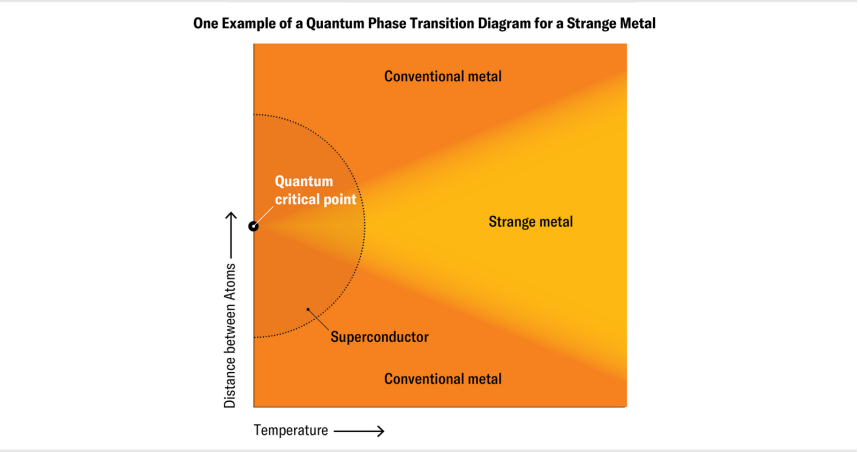
In recent years physicists have found a dozen or more materials that are clearly metals, in the sense that their electrical resistivity decreases with decreasing temperature, but that are *not* Fermi

liquids. These “strange metals” have resistivity at low temperatures that is linearly proportional to temperature—that is, their resistivity varies with the actual temperature rather than with the square of the temperature. Examples of these materials include some copper oxide superconductors, some iron-based superconductors, some “heavy fermion” materials, and twisted bilayer graphene under certain conditions.



Credit: Jen Christiansen

Most of these arose from laboratory experiments looking at materials known to be near a transition between phases (such as between a superconductor and a metal or between different magnetic states). At first glance, these strange metals don’t appear very remarkable. Although they tend to be hard and brittle rather than soft and ductile, their “strangeness” is not apparent at room temperature, because thermal energy swamps the quantum effects when these materials are warm. Many materials seem to be perfectly ordinary metals until they are near a particular quantum critical point, in terms of temperature, pressure, and other parameters. At this critical point, if the materials are near absolute zero (in their ground state), they switch between two different phases—for example, two ordinary metals with different magnetic properties. At higher temperatures and energies, they turn into strange metals.



Credit: Jen Christiansen

Whether the resistivity depends on T or T^2 at low temperatures may sound like an innocuous difference, but it's not. This change implies the failure of Fermi liquid theory and, some scientists think, the breakdown of the quasiparticle picture of excited electrons. In the absence of quasiparticles, it's as if the electrons lose their individuality and act collectively as a strongly interacting soup in which all the particles are highly entangled. Entanglement is a kind of quantum connection that makes particles' fates intertwined. And when the electrons within a metal become strongly entangled, their collective behavior changes.

One fascinating outcome is that the timescale on which the electrons distribute momentum among themselves in many (but not all) strange metals is "Planckian," meaning it is essentially governed only by quantum mechanics (through what's called Planck's constant) and temperature, independently of any details of the materials. This kind of universality among all strange metals, and the fact that strange metallicity appears in many different materials, suggests there is some deeper organizing principle at work. Theoretical models describing strange metal phenomena can tend toward the exotic. Some models even map the electron behavior to the physics of event horizons around black holes.

This is the kind of fun challenge that inspires experimentalists. What measurements can we do, beyond resistance versus temperature, to see what's going on microscopically in strange

metals? How can we tell whether the electrons are acting cooperatively in some weird quantum soup or as nearly independent electronlike quasiparticles? There is a puzzle-solving aspect of experimental physics: How can we use a limited set of tools to distinguish experimentally between different models of what might be going on, given that we can’t watch every electron?

In my view, there are four particularly promising experimental avenues for probing strange metals. One approach involves using a beam of electrons to deliver precise amounts of energy and momentum to the electrons within the metal, a process called momentum-resolved electron energy-loss spectroscopy. By mapping out how the entire electronic system can absorb energy and momentum, physicists can distinguish between contributions from conventional quasiparticles and those from a collective quantum response.

A second technique relies on recently developed, very precise methods for studying how a current flows within a material. In this approach, physicists employ incredibly sensitive magnetic field sensors. One sensor is a superconducting ring (a superconducting quantum interference device, best known as SQUID) that generates a voltage precisely related to the amount of magnetic field that flows through the ring. Another sensor is made of a diamond crystal with a particular defect—a nitrogen atom next to a spot where there should be a carbon atom but isn’t (a “nitro-gen vacancy center”). Its optical properties are quite closely linked to the local magnetic field, making it a good field sensor. By mapping out the magnetic fields near a strange metal, researchers can infer the detailed local flow of current, including signs of electrons cooperating, with the sea of electrons acting like a fluid with very low viscosity.

A third method uses optics techniques to investigate the transmission and reflection of light with wavelengths between about 100 nanometers and one millimeter. Researchers use this

approach to infer how the electrical conduction process, including scattering, depends on the frequency of the electric field. The relations among conductivity, frequency and temperature can give greater insights into whether the material is Planckian.

The fourth approach, which we use in my lab, is to measure “shot noise” in the current flowing through a strange metal. Shot noise is related to the granularity of electronic charge. If a current is carried by discrete charge carriers (such as individual electrons or quasiparticles), as opposed to a continuous soup, statistical variation in their arrival times leads to fluctuations in the current. Consider raindrops falling on your roof. The same amount of water per unit time can arrive as a smooth, steady rain of many small drops or as a strongly fluctuating shower with fewer but much larger drops. Measuring the current fluctuations gives us information about how much charge is transported at a time.

Our measurements are possible only because we use high-quality films of one strange metal, a compound with the chemical formula $YbRh_2Si_2$, developed by our collaborators at the Technical University of Vienna in Austria. This material has a quantum critical point between two distinct Fermi liquid states that becomes clear and sharp at temperatures less than 50 thousandths of a degree above absolute zero, depending on the magnetic field. In my lab, we created nanoscale wires from these films and watched the shot noise in the current. At the temperatures of our experiments, three kelvins up to 10 kelvins, this material is very much in the strange metal regime. If the electrons in this wire flowed more like a continuous fluid rather than a stream of discrete quasiparticles, the shot noise would be lower than that of a Fermi liquid. We did in fact measure a suppressed shot noise in our strange metal, whereas control measurements on gold wires showed the expected Fermi liquid results. Our measurements don’t yet line up with a definitive theoretical model for what’s going on in strange metals, but they help to point us in the right direction for one.

Strange metals present an apparent failure of one of the most successful physics models of solids. For physicists, this failure is a great temptation for exploration. Yet these metals are not just a topic of purely curiosity-driven basic research. They could potentially be important for urgently needed technologies. Scientists have observed superconductivity emerging in multiple families of strange metals at relatively high temperatures. Understanding these metals may help us develop superconductors that might operate at or close to room temperature, potentially transforming power grids, quantum computing and medical devices. If our explorations of the strange frontiers of solid-state physics are successful, there is always a chance that the next epoch of technology will come to be known as the Strange Metal Age.

Douglas Natelson is a professor of physics at Rice University, where he studies the emergent properties of materials. He writes the condensed matter physics blog Nanoscale Views.

Families Find Ways to Protect Their LGBTQ Kids

Hostility toward LGBTQ kids, enshrined in hundreds of new bills, has put families with such children under unprecedented threat, raising risks of suicide and physical attacks

By Marla Broadfoot

Simon, a gay teen, stands with his parents. His courage means “I need to be fearless,” too, his mother says.
Gioncarlo Valentine

Tamara had not been sleeping well. Some days she woke up at four o’clock in the morning in tears and overwhelmed by a feeling of

helplessness. She had moved her family three times over the past six years. Her house in New Hampshire was shot at—possibly by someone aiming at the rainbow signs in her front yard. In 2022 she fled to Massachusetts, which seemed to be safer for her child, Grey, who is transgender. But whenever she hears the words “safe state,” a thought pops into her head: “Austria felt like a safe place in World War II, too.”

For the time being, Grey feels like they are in a good place mentally. (For their personal safety, the names of young people and their parents in this story have been changed.) They have found a community that sees them for who they are and a state that allows them to receive the gender-affirming care they need. But they have seen dark times before, and the familiar drumbeat of anxiety never quite goes away. “I am always a little concerned in the back of my head that things are getting kind of bad in some places, and maybe that’ll happen to me,” Grey says.

For many families with LGBTQ kids, the dark times are now. More than 500 anti-LGBTQ bills were considered in state legislatures in 2023, and 84 passed. (The term “LGBTQ” refers to lesbian, gay, and other people with minority sexual orientations and gender identities.) These bills restrict discussions of LGBTQ people or history in schools, limit legal protections for queer and transgender youth, and prohibit transgender health care for minors and even adults.

The sheer volume of these bills, and the sentiment behind them, is doing harm. An estimated 71 percent of LGBTQ youths—including 86 percent of transgender and nonbinary kids—say that laws concerning LGBTQ people have had a negative impact on their mental health. Nearly half of LGBTQ kids seriously considered suicide in the previous year, according to a survey conducted in 2022 by the Trevor Project, a nonprofit group that offers crisis services.

Discrimination against LGBTQ kids is also taking a toll on parents' mental health, and the added family stress can make things even worse for their children. Studies show that family support is critical to the psychological resilience of queer and trans kids. But many parents are filled with fear, grief and anxiety, and the strain makes it harder for them to shield their children from the harshness of an often hostile world. "No one can be empathic with your fists clenched," says Lisa Diamond, a psychologist at the University of Utah. "I've come to believe that we cannot help LGBTQ youth without taking stock of the amount of vigilance and worry that is eating up the nervous systems of their parents. You can't heal one without the other, because if that kid really matters to you, there is no way that their fear can't make you afraid."

In reporting this story, I spoke with 20 parents, and some of their kids, in North Carolina, Georgia, Texas, Florida, Ohio, California, New York and Massachusetts. Our conversations revealed just how widespread their fears are. Tamara, Grey's mom, tried for months to stop anti-LGBTQ bills when she lived in New Hampshire. She and others were spit at and called "groomers" and "pedophiles" after speaking at a legislative session. Then there were the bullets grazing her house.

Still, families are finding ways to cope. A grassroots movement is creating safe spaces for parents, such as online communities that enable parents and caregivers to support one another and networks to help them find LGBTQ-friendly places to raise their kids. They

are crafting positive narratives, focused on their families, filled with strength and growth and hope. Those narratives are helping them make meaning from their hardship while envisioning a future where their loved ones are no longer under attack.

Francis came out to their family as pansexual and nonbinary in 10th grade, with a group text. The text explained that they would prefer to be called by a new name and referred to with they/them pronouns, and although they didn't expect their conservative Catholic family to understand, they hoped their relatives would respect their wishes.

"I was terrified," Francis recalls. They had been seeing a therapist for years, but the counselor wasn't well versed in LGBTQ issues. "I knew I needed to come out so that I could get further support, whether that be from another therapist or somebody in my family at least recognizing my pronouns and my name," Francis says.

The first texts Francis got back from family members were positive: "we love you for who you are." But within a few months they learned that their parents had quite different feelings. Their dad ignored the issue, staying silent rather than using Francis's new name and pronouns. Their mom, Lois, kept questioning what it meant for them to be nonbinary or trans. She knew people who were trans, "but when it is your own kid," she says, "it seems so different."

Given the large number of young people who identify as LGBTQ—about 25 percent of high school students are not heterosexual, according to a 2021 survey—remarkably little research has focused on the experiences of their parents, says David Huebner, a clinical psychologist at the George Washington University. The queer community has compensated for lost family ties with the narrative of a "chosen family": even if your parents reject you, you can depend on other LGBTQ people, who become like siblings. That

sentiment might work for adults, but it doesn't ring true for minors who rely on their families for even the most basic needs.

In 2009 Huebner and Caitlin Ryan, director of the Family Acceptance Project at San Francisco State University, published one of the first studies showing that parents' attitudes matter a lot. The research found that lesbian, gay or bisexual teens who were rejected by their parents or caregivers were eight times more likely to attempt suicide than those who were accepted.

But parents' reactions don't necessarily fit into the simplistic binary of rejecting or accepting. "It's a journey, a very bumpy journey," says Roberto Abreu, a psychologist at the University of Florida. Abreu and others have shown that parents can experience a gamut of emotions after their kid comes out as queer or trans—shock, confusion, sadness, worry, guilt, fear, grief, anger—and it can take two years or more for those emotions to abate. They often feel overwhelmed by the disconnect between their earlier beliefs about their child's identity and what that child is telling them now. The burden of navigating schools, health care, and other systems to support their child adds to the strain.

"There's just a lot of stress and anxiety around the unknown; like, what am I supposed to do?" Lois says. She and her husband held wildly different views on gender and how to care for Francis, which caused a fracture in their marriage. "It's like walking on glass. It's really scary," she says.

Some parents grieve the loss of the child they thought they had and their visions for that child's future. These expectations are often tied to outdated conceptions of gender and sexual orientation that are being challenged as more people come out as LGBTQ and expand our understanding of human experience. For example, gender is not necessarily fixed at birth. A study in *JAMA Network Open* found that most transgender children sense a mismatch between their biological sex and their gender identity by age seven.

Sarah, the mother of a six-year-old transgender girl in New York State, still feels a pang whenever she comes across something adorned with her daughter's male birth name, which many trans people call a deadname. She and her husband named each of their children after a relative who had passed away to keep the memory of their deceased loved ones alive.

"That's a complicated thing for parents, I think, because how can you feel grief over something that clearly your kid is experiencing joy over—being their true selves?" Sarah says. Sarah recalls reading somewhere that grief is just love with no place to go, and those words resonated with her.

Unresolved grieving for a person who is still present yet different is an experience that psychologists sometimes refer to as ambiguous loss. In families of LGBTQ children, such loss may affect not just the parents but also their kids. Work led by Jenifer McGuire, a professor of family social science at the University of Minnesota, suggests transgender children can experience ambiguous loss when their family responds to their identity in conflicting ways. Family members might remain physically present but become psychologically absent, ignoring the gender transition and prompting a sense of loss in the children.

Grey, who is nonbinary, gets support from their father and mother. The family has had to move several times because they felt unsafe.
Credit: Gioncarlo Valentine

For Francis, there was a certain amount of sadness when their expectations of what life would be like after coming out brushed up against reality. They transferred to a new high school, where they met some like-minded friends. Their mom got them into a gender clinic in Ohio, where they were referred to a psychologist who helped them address their distress at the mismatch between their gender identity and their sex assigned at birth. Psychiatrists, after thorough consultation, recommended they start their medical transition with hormone treatments. But during one appointment, Francis's dad said he thought what they were doing was wrong and insisted they forgo treatment.

“It was really earth-shattering,” Francis says. “I had been very sad about a lot of things, about not being accepted by everybody. But when he had completely shut it down, I was very, very angry. We’ve gone through the other possibilities, we’ve gone through the other options, and all the doctors are telling you that this is what needs to happen.”

Every major medical association in the U.S., including the American Academy of Pediatrics, the American Medical Association and the Endocrine Society, endorses gender-affirming care for trans kids. Such care ranges from counseling to social affirmation to medical interventions such as hormone therapy. Numerous research studies have linked this form of care to better mental health. For example, one study looked at nearly 22,000 trans people nationwide who sought hormone therapy. It found that those who started receiving hormones as teens had fewer suicidal thoughts and a lower rate of substance abuse than those who were forced to wait until adulthood.

Still, Francis was afraid to argue with their dad. Lois, their mom, promised she would never let their dad kick them out of the family home, but Francis wasn’t so sure. “The scared part of me was [thinking]: Don’t say too much. Because I still need a place to live. I still need a safe space.”

Lois was angry and scared, too, and worried that Francis would lose hope. She reminded them that they would turn 18 in a little more than a year and suggested they make a calendar to count down the days.

Francis put the date into their phone, but seeing the time tick by in an interminable number of hours and minutes only fueled their anxiety. So they bought several packs of colorful Post-It notes, numbered each for the hundreds of days they had left until the birthday that would give them independence and pasted them all

over one wall of their bedroom. “It was a bizarre thing to do,” Francis says. But the notes kept them going.

Compared with other kids their age, LGBTQ youths are at higher risk of numerous mental health issues, including depression, anxiety, substance abuse, self-harm and suicide. These health issues have been largely ascribed to minority stress, the consequences of social sources of tension that come with a marginalized identity. These stressors are not an innate part of an LGBTQ identity. Rather they emerge from experiencing repeated prejudice and powerlessness.

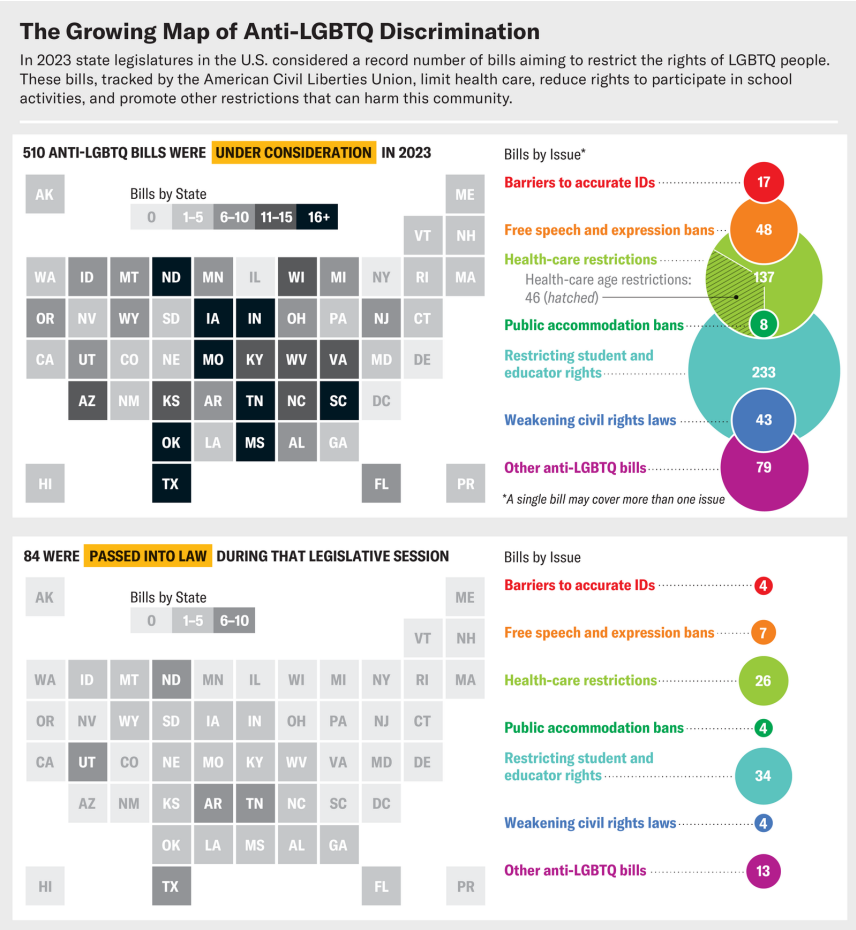
Now some researchers believe that the minority stress theory should be expanded to include parents of queer and trans kids, who experience a loss of privilege and normalcy and contend with oppressive institutions on behalf of their family. In a small study of 40 parents of transgender children, parents reported experiencing rejection from their extended family, as relatives refused to learn about their children’s transition or criticized their parenting. They feared being mistreated by friends, other parents and their community for not enforcing societal norms surrounding gender identity.

For many families, the moment a kid comes out of the closet, the parents get into the closet, unsure of how to deal with a secret that is not their own. When Cristina, a mother in North Carolina, first learned that her oldest kid was bisexual, she worried about how the members of her conservative church would react. “There was a lot of fear. I didn’t want people to know; I didn’t know how to frame it,” she recalls. “I was just terrified that I was going to be cast out of my circles and not supported if I supported my kid. So I went underground with that info.”

This type of anticipated rejection or stigma is a key driver of minority stress. Coming out is often considered a lifelong process because people who are queer or trans must constantly negotiate

how openly they want to exist in society, deciding whether they should share that aspect of their identity or keep it to themselves. “One of the things that is associated with negative mental health outcomes for LGBTQ people is concealment. And concealment is basically the flip side of outness,” says Josh Goodman, a psychologist at Southern Oregon University. “The same thing goes for parents, too.”

Simon, a gay teen, recalls how as a child he would hide his dolls whenever guests visited. Although he expected his parents to be supportive, he says it was still hard to tell them he was gay, “like pulling a knife out of your throat.” When he was in the seventh grade, he was at a neighborhood convenience store when a man called him a “disgusting f****t.” Simon put down the drink he was about to buy and walked straight home. Every time he goes back to that store, which he does often, he feels a little sick to his stomach. “That moment is instilled in my mind.”



Credit: Jen Christiansen; Source: American Civil Liberties Union (*data*)

His mom didn’t learn about the episode until weeks later, and when she did, she was filled with guilt that she somehow had allowed it to happen. She decided to send Simon to a more progressive, accepting high school one county away. She started daring herself to tell people he was gay, as if educating those around him were a talisman against future harm. And she tried to follow his lead whenever possible. “If he’s going to be fearless, I need to be fearless,” she says.

Fear is a major source of stress for many parents of LGBTQ kids. They worry their kids will be lonely, suffer from poor mental health, and experience violence or victimization. And those worries cause parents to react in ways they are not always proud of. One mother told me she cried when her daughter came out to her as bisexual: “I just knew that her life was going to be so much more difficult.”

This notion that being gay means pain and suffering reinforces stigma, yet it has some basis in reality. According to a 2023 study by the Trevor Project, 24 percent of LGBTQ youths reported that they were physically threatened or harmed in the past year because of either their sexual orientation or their gender identity; those who were threatened or harmed also reported attempting suicide at nearly triple the rate of those who were not.

Jacqueline, a mother of two in Florida, was roused from her sleep one September morning as the telephone persistently rang several rooms away. The mother of a friend of one of her children, Adrian, was on the line. She wanted to know if the youngster was okay. Adrian had texted suicide notes to that friend and others in the middle of the night. Jacqueline rushed out of her room and found Adrian lying on the floor, convulsing. On the ambulance ride to the hospital, her mind was a jumble of worry and dread.

“Is Adrian going to be okay? Is there going to be brain damage? I didn’t know,” Jacqueline recalls. “I was in shock. I thought, I can’t

believe this is happening; I just cannot believe this is happening."

Adrian had come out as trans to their parents the year before, when they were 14. Adrian's father, who came from a conservative background, consistently misgendered them. The boys at their school were all bigger and appeared more masculine, and they felt like their gender was constantly being questioned. Eventually it got to be too much, and Adrian sent those texts.

Five years later and after many hours spent under the care of medical professionals, Adrian is doing well. They're a junior in college, living in an apartment with their older brother 15 minutes away from their parents. Their father finally accepted their identity. Jacqueline texts them every day, and if they sound "off," she rushes over to see them. "I always worry," she says. "I'm still scared that something might happen."

Diamond, the University of Utah psychologist, says this hypervigilant state can be devastating to parents. She has studied minority stress in members of the LGBTQ community and in their caregivers, and she believes the absence of safety erodes their mental health. The same response designed to protect humans from the proverbial saber-toothed tiger is now perpetually activated by headlines signaling that LGBTQ kids are threatened.

"We humans need to feel a sense of belonging—it's our birthright as a social species," Diamond says. "When we feel that there's something about us or our family that's off, then we just go into that evolutionary state of watch out." Diamond's work suggests that being in that constant state of uncertainty could be as detrimental to a person's overall well-being as experiencing a traumatic event. Her research indicates that all this worry can cause some parents to become more controlling and authoritarian, driven by the desire to protect their kids from danger or judgment.

For example, parents might keep their kids from LGBTQ-centric events such as Pride parades or discourage them from publicly disclosing their pronouns. Even if the intention is to protect, these tactics can create a vicious cycle. One recent study linked higher levels of parental psychological control—that is, trying to coerce kids into thinking or behaving differently—with more depressive symptoms among LGBTQ youth.

Looking back, Tamara regrets how she insisted on constantly cutting Grey's hair and nails, nervous about what would happen if they didn't adhere to the gender norms of the rural Texas town where they first lived. Although Grey recalls being bitter about it at the time, they can see now why their mom thought their identity had to be kept under wraps. "You don't necessarily want to be the weird feminine one mixed in with that group of people," Grey says. "She wasn't really making a bad decision in my mind. It's hard to figure out what to do because both decisions are kind of hurtful, just in different ways."

In helping their kids embrace their authentic selves while trying to keep them out of harm's way, parents of LGBTQ youth are walking a tightrope between freedom and safety. That act is getting even trickier as anti-LGBTQ legislation sweeps the nation. "I think the burden of these bans, and stigma and discrimination more broadly, on the population is even bigger than we estimate," says Kerith Conron, research director at the Williams Institute, based at the University of California, Los Angeles, School of Law. "It's not just the individual; it's these broader ecological ripple effects."

Researchers working to understand the child-parent dynamic have been harassed by some of the same groups trying to make the lives of LGBTQ people and their families so miserable. Last year Abreu, the psychologist at the University of Florida, partnered with Russ Toomey, a developmental scientist at the University of Arizona, and the Human Rights Campaign (HRC) Foundation to conduct the first large-scale, national study of parents and caregivers of trans

and nonbinary children. The study gathered parents' perspectives in a variety of contexts, asking about their mental health and their child's gender identity development, the barriers they faced and the support systems that helped them. The researchers shared the survey through the HRC Foundation and online groups where parents of trans youth congregate. More than 1,400 parents responded.

But anti-trans groups got ahold of the survey and sent hostile e-mails to Abreu and Toomey. One group penned letters to their universities' presidents and institutional review boards, as well as boards of regents, governors and heads of the departments of education in both states, claiming the research was unethical and was harming youth. "That's the first time I've ever had an outside entity file a grievance against the ethics of research that I have engaged in in nearly 20 years," Toomey says. "That professional attack is quite jarring to take."

Toomey is working on publishing the study results. He hopes the research will inform policies to better support and educate the parents of trans youth.

Unlike parents of children in many other minority groups, most of those raising queer and trans kids don't have lived experiences to inform them and are often unsure how to support their LGBTQ offspring. So they are turning to peer-support groups. PFLAG, formerly known as Parents, Families and Friends of Lesbians and Gays, runs such groups, and many parents have found a sense of purpose and belonging that has helped them strengthen relationships with their children. But some parents aren't comfortable talking about these issues in a group setting. Others live in communities without a local chapter; according to some estimates, only about 10 to 15 percent of parents of LGBTQ children ever make it to a PFLAG meeting.

Instead many parents gather virtually, seeking crowd-sourced advice from Reddit or joining one of countless Facebook groups. Every day these platforms are filled with posts from parents searching for information and a sense of community. They are looking for recommendations on affirming churches and therapists; asking for guidance on sex talks and same-sex sleepovers; talking through experiences with school bullies, haircuts and hormone therapies. These online communities can help parents navigate this journey, giving them a place to open up to other parents who have been in their position before and can show them what's ahead. More experienced parents can correct commonly held misconceptions and connect newcomers to resources that can help them better understand and support their kid.

One such online community, called Mama Bears, started in 2014 with 150 members, most of them conservative Christians. Cristina, the mom in North Carolina, was one of them. She says the group supported her as she reexamined her faith, a process that was often frightening and messy. "[We were] holding each other up but at the same time challenging each other to continue moving forward," she says, "to start learning about what acceptance of your kid really means."

Today Mama Bears is more wide-ranging, with more than 39,000 members and various programs serving the greater LGBTQ community. Liz Dyer, the group's founder, says she has seen a complete shift in the conversations parents are having, moving from topics such as religious acceptance to concerns about protecting their children. "Mothers are very worried. But what we have found is that knowledge and education really empower parents. And once they feel more empowered and capable and knowledgeable, a lot of their anxiety—I don't want to say it dissipates, but it's easier for them to cope with."

In addition to the communities parents are building for themselves, some LGBTQ-focused organizations are expanding their services

to help families. In Austin, Tex., a small nonprofit called Out Youth has created several programs for parents, including “family office hours” that offer hour-long counseling sessions for caregivers and family members. It also started caregiver-support groups, which provide a six-week crash course on parenting a trans, nonbinary or questioning child. And Out Youth piloted a caregiver peer-support program, which paired more experienced parents of trans kids with those whose kids had just come out.

“The thing that I’ve learned, and that I’ve said from the beginning of doing this work, is that caregivers and their young person are on separate yet intersecting journeys,” says Sarah Kapostasy, who formerly served as Out Youth’s clinical director. “Sometimes caregivers need a separate space.” If parents have a place where they can figure things out away from their family, it can keep their kids from being burdened by negative feelings those parents are going through and from taking on such feelings about themselves.

Eventually many parents experience a kind of positive transformation as they adjust to their child’s identity, research suggests, and they often end up redefining their own identity as the parent of an LGBTQ kid. Dani Rosenkrantz, a psychologist and researcher in Florida, says that although parenting a trans kid is often cast as a hard role filled with grief and pain, she has heard a more positive narrative emerge lately about parents witnessing their worldviews expand and their children flourish.

“I have learned so much from my child, and I just feel very proud of who she is and how she’s had the courage to speak that truth,” Sarah, the mother in New York, told me. “We owe it to our kids to make a more informed, enlightened world for them.” One study by researchers at the University of Kentucky set out to catalog the positive aspects of parenting an LGBTQ child. The survey of 142 parents uncovered various ways the experience brought about parents’ personal growth. It made them more compassionate, gave them greater empathy for marginalized populations, strengthened

their relationship with their children, connected them more fully to their values, led to lasting friendships, and motivated them to engage in activism and advocacy.

But trying to make the world a better place for their own kids and the rest of the LGBTQ community can expose families to hatred and danger. One parent in Georgia told me that after she organized the first Pride celebration in her town, she received warrants for her arrest listing a dozen city and state violations, among them "enticing a child for indecent purposes." (The charges, which were traced back to a right-wing activist organization, were dismissed by a judge before being brought to trial.)

Adrian, a transgender youth, shares a hug with their mother.
Credit: Gioncarlo Valentine

Another parent, a single father to a 12-year-old trans boy in Florida, says he can no longer protest anti-LGBTQ bills, because it raises risks of repercussions for his child. "You always balance out your ideals, your principles, your goals as a citizen with the needs of your family," he says. He has developed an exit plan in case his home state becomes even more hostile. He has passports ready and is prepared to quit his teaching job and start his own company, moving to another state or abroad if necessary. Being able to think

about leaving, a privilege he recognizes many parents do not have, has bolstered his mental health.

To help families of trans kids move to safer places, volunteers have created relocation networks. There are GoFundMe pages to help cover moving costs, and allies post information in a variety of locations to connect parents to good school districts, friendly neighborhoods and affirming-health-care providers. Parents can consult various color-coded maps to see which states are safest, such as the LGBTQ Equality Maps drafted by the Movement Advancement Project, a nonpartisan think tank.

Mama Bears has created a relocation-assistance program to contribute to the effort, but Dyer says she hopes parents use it only as a last resort. “It is not going to help the movement to set trans people free if everybody that is affirming abandons red states.”

Tamara has heard that concern several times since moving her family to Massachusetts. But she doesn’t regret her decision, which she knows was best for Grey and for her and her husband, too. “For us, our mental health is aligned with our kid’s mental health,” she says.

Yet even now, in an apparently safer place, she and her husband still find themselves trying to protect Grey from the news, transphobic relatives and hostile people on the street. Recently the three of them went for a walk through their city. Tamara noticed that they had fallen into “bodyguard mode”: one parent in the front, one parent in the back and their only child in between.

Marla Broadfoot reported this story while participating in the Rosalynn Carter Fellowship for Mental Health Journalism.

If You Need Help

If you or someone you know is struggling or having thoughts of suicide, help is available. Call the 988 Suicide & Crisis Lifeline at 988, use the online Lifeline Chat, or contact the Crisis Text Line by texting TALK to 741741.

Marla Broadfoot is a freelance science writer who lives in North Carolina. She has a Ph.D. in genetics and molecular biology.

Old-Growth Forests Know How to Protect Themselves from Fire

People keep trying to help old-growth forests survive fire by cutting trees, even though the forests have done fine on their own for 1,000 years

By Alexis Marie Adams

A creek winds through vibrant forest in Montana’s wild Yaak region.
Hunter D’Antuono

In Montana’s northwestern corner, centuries-old trees rise to a late September sky: ancient cedar, giant hemlock, shaggy sharp-needled spruce. Western larch, which can live for 1,000 years, tower above. Early morning’s light, filtered through the multilayered canopies, shimmers green and iridescent as it hits the forest floor, where bright ferns and mushrooms sprout from a carpet of blue lichen and emerald mosses. Mammoth fallen trees are slick with moss, their exposed root balls as big and round as a Volkswagen Beetle. The ground is so spongelike and moist that it squelches underneath my boots. A breeze moves through the overstory more than 150 feet above, and the forest creaks. A raven calls. A distant woodpecker

drums its beak into a tree’s thick bark, foraging for beetles and ants. Otherwise this old-growth, primary forest is quiet.

Deep in a remote and rugged region known as the Yaak, this 192-acre expanse I am walking, unceremoniously called Unit 72 by the U.S. Forest Service, offers a rare glimpse of an original arboreal landscape. This is what the forests that cloak the surrounding mountains and valleys looked like before the axe and the chainsaw. For decades much of the region has been stripped of its timber, yet this lush section of old-growth forest appears to have never been logged, and there is no evidence that it has burned.

This stand, and a few others like it remaining in the Yaak, is vital habitat for grizzly bears and other threatened and sensitive species, as well as more common wild creatures and plants. Elk, moose, gray wolves, Canada lynx and the diminutive northern bog lemming (weighing in at a mere ounce) live here. Mayflies rise in clouds from the marshes and streams where otters play. Trumpeter Swans soar above.

Winters across the Yaak are typical of the Northern Rockies: bitterly cold with deep snowpack. But in the spring and fall, maritime weather drifts in from the Pacific Northwest, bringing clouds, fog and drizzle. The convergence of the two weather patterns results in a confluence of flora and fauna. As I step, I see the same tree species that grow along the coasts of Washington

State, British Columbia and southeastern Alaska. I also see the lodgepole and ponderosa pines that thrive in the Rockies.

The name “Yaak” is derived from the native Kootenai term for “arrow” or “bow”—the same name given to the river that flows through the heart of this region. The USFS considers the Yaak River’s watershed—roughly 398,000 acres that touch Idaho to the west and British Columbia to the north—as the Yaak region, even though locals say it reaches much farther. Just 3 percent of the watershed is privately owned; the rest is part of the 2.2-million-acre Kootenai National Forest.

Logging began in the Yaak in the early 20th century with small-scale, family-owned mills. By the 1990s large corporations had replaced many of the local operations, and they have logged aggressively since then. In some areas, trees are selectively cut and removed, with others allowed to remain. Some tracts are clear-cut, leaving vast swaths of bare ground, desiccated streams and marshes, and countless tree stumps. Thousands of acres of the Yaak’s old-growth and mature trees have been clear-cut in the past 40 years.

The USFS manages national forests and grasslands on public lands across the country. The agency, housed under the Department of Agriculture, has long had a reputation for managing forests as crops. In 1986 timber was the highest-valued “crop” in the nation, a USFS report noted. The agency sells areas of forest—sometimes at below-market prices, according to various reports—to private logging corporations, sometimes at the expense of valuable ecosystems. The corporations harvest the wood and truck it away for profit. Today less than half of the Yaak’s primary forests remain uncut. Yet there is no official designation in place to protect the wild places that still exist.

Western red cedar (*large tree*) can grow to more than 200 feet tall, 20 feet in diameter and 1,000 years old. Timber companies seek the tree's wood for decking, shingles and siding.
Credit: Chris Balboni

In the Yaak, the USFS has proposed or begun five major logging initiatives covering more than 300,000 acres in the Kootenai National Forest. For years various agencies, experts and politicians have promoted logging to prevent fire; a thinned forest, they argue, means there is less fuel to burn. The approach has been criticized, and fought, for just as long. One of the five projects, called Black Ram, was proposed in 2019 for the Yaak and blocked in August 2023 by a U.S. District Court judge ruling. Environmentalists say the 95,412-acre project, almost a quarter of the Yaak River watershed, would have allowed logging in hundreds of acres of old-growth forest—including Unit 72.

The potential loss is deeply unsettling to Rick Bass, my guide through Unit 72. Employed long ago as an oil and gas geologist, Bass is known to some audiences as an exceptional writer of literary fiction and essays often set in this wild region. Other people know him for his activism in defense of the Yaak. Bass the writer has published dozens of short stories and more than 30 books. He's won multiple prizes and fellowships, including a Guggenheim Fellowship and a National Endowment for the Arts Literature Fellowship. Bass the activist has written editorials and articles about clear-cutting and roadbuilding in the Yaak, filed

lawsuits against the USFS, and been arrested for civil disobedience multiple times, once in front of the White House.

Bass moved to the Yaak Valley from Mississippi at age 29 with his then partner, painter Elizabeth Hughes Bass, as they searched for a place to make their lives and their art. He describes the couple's first season in *The Book of Yaak* (Houghton Mifflin, 1996). "We traveled through July thunderstorms and August snowstorms until one day we came over a pass and a valley appeared beneath us," he writes, "a blue-green valley hidden beneath heavy clouds, with smoke rising from a couple of chimneys far below, and a lazy river snaking its way through the valley's narrow center, and a power, an immensity, that stopped us in our tracks."

Characters in Bass's fiction hunt elk, deer and grouse. They fish the valley's rivers and streams, they forage for berries and mushrooms, they gather firewood for the long, dark winters. These are not hobbies for his characters; they're imperatives. Drawn to live in this sparsely populated valley, an hour's drive on the easiest of days from the nearest doctor, grocery store, liquor store or post office, the characters are solitary and self-reliant, yet they are bound together by their shared craving for independence, wilderness and quiet, their shared love for this place, and their shared fluency in its ways.

Off the page Bass and his neighbors live the same way. Bass's understanding of the land, his deep and intimate relationship with it, is evident as we hike. At 66 he is nimble and lithe as he scampers over the slippery carcasses of fallen trees and ducks under lodgepole pine blowdown, all the while pointing out species of trees and birds and answering my questions about forest policy, the ecological complexity that surrounds us and the fire resilience of old-growth woods.

We stop often, crouching to look at tiny ferns, bright orange mushrooms and elk scat. Huddled over a fungus that Bass says he's

never seen before, we notice a diminutive pygmy slug—a species, he tells me, that is not yet threatened but could be—making its long way over a rotting log.

At one point, when Bass is about 10 yards ahead of me, he shouts, “Oh, my god! Oh, my f------ god!” And then, “Come look at this!” As I reach him, he points to an enormous moose shed—a magnificent antler leaning against a downed tree, cast off by a male moose during the winter shedding season. One corner of it has been nibbled by some creature. “It’s a big one for this country. It’s huge! It’s one of the most beautiful things I’ve ever seen,” Bass says with enthusiasm and wonder. “It’s like a holy relic, as poetic a declaration to the Yaak’s wildness as anything.”

But then he grows quiet and points to the broad trunk of an ancient larch in a grove behind the moose shed. It’s been spray-painted with bright orange stripes—indicating that this stand of old-growth forest had been slated to be cut.

Bass describes Black Ram as a “holdover” of the Trump administration. In 2018 then President Donald Trump mandated increased logging in national forests, ostensibly to reduce wildfire. In 2021 another Trump-era rule went into effect allowing logging of old-growth stands in six national forests. Last September, Senators Joe Manchin of West Virginia and John Barrasso of Wyoming introduced bipartisan legislation to “reduce catastrophic wildfire risk and improve forest health,” largely through aggressive cutting.

Author and activist Rick Bass questions the practice of cutting down trees to lessen fire risk. Old-growth forests, he says, have survived wildfire for centuries without any human “help.”
Melanie Maganias Nashan

“They say they’ll log this old-growth forest—this wet, green *rainforest*—to create fire resilience,” Bass says, “but these trees are already fire-resilient. This larch, for example, is not only meant to survive fire; it’s meant to prosper from it. These attributes, the species diversity here, the structural diversity of the forest—they need to be studied, not clear-cut. But the Forest Service says that by clear-cutting a, what, nearly 1,000-year-old forest, they’ll teach it to be resilient?”

On Earth Day (April 22) in 2022 President Joe Biden issued Executive Order 14072, mandating an inventory of old-growth and mature forests on federal lands across the U.S. The order's purpose was to create a policy to protect old forests. But even as the USFS and the Bureau of Land Management were tallying the trees, the two agencies continued to plan and implement logging projects like Black Ram in mature and old-growth forests across the country. These included nearly 10,000 acres of mature forest in Kentucky's Daniel Boone National Forest and 54,883 acres of mature and old-growth trees in the Bitterroot National Forest, which extends from Montana across the Idaho border, roughly 250 miles south of the Yaak Valley. Bass says the Forest Service shows no sign of slowing down: "It flies in the face of the administration's goal to conserve old-growth forests on public lands, not to mention the administration's climate goals."

The vast majority of old-growth forests in the U.S. have been logged, according to Dominick A. DellaSala, chief scientist at Wild Heritage, a project of the Earth Island Institute, and former president of the North American section of the Society for Conservation Biology. The untouched areas that remain include California's 2,000- to 3,000-year-old giant sequoia and coastal redwood forests, northern Wisconsin's 40-acre grove of 300-year-old hemlock and pine, and the scattered remnants of the 250-year-old post oak groves of the Western Cross Timbers forest, which once stretched from north-central Texas all the way into southern Kansas.

Perils exist worldwide. One of Europe's last old-growth forests spans the border of Belarus and Poland, a remnant of the vast primeval woods that once cloaked the European plain; most of it is now threatened by logging, despite its also being a World Heritage site. There have been successes, too. The ancient temperate rainforest of Yakushima, Japan, prized for its cedar trees that are well over 1,000 years old and its extraordinary biodiversity, has been spared.

That Unit 72 ended up in danger is not a surprise to Bass. Twenty-seven years ago he and other residents of the valley founded the Yaak Valley Forest Council to protect the region's remaining roadless areas and other critical habitat from roadbuilding and clear-cutting. When the USFS announced Black Ram, the council's staff, board members and volunteers rolled up their sleeves yet again and got to work.

One of the council's strategies was to prove the region's old forests were indeed "old growth" and to demonstrate the forests' capacity for carbon storage and fire resilience. The definition of old growth varies and can depend, in part, on the agency or organization doing the classifying. Most descriptions emphasize the forest's age, its capacity to support exceptional biodiversity and its structural complexity—the presence of multiple features such as a multilayered canopy; a damp, hummocky forest floor; and standing dead trees and downed wood that create moist, fertile habitat for seedlings, fungi, insects and wildlife. Old growth can overlap with what's called primary forests: woods of any age that have never been subjected to any industrial activities. According to the United Nations Food and Agriculture Organization, since 1990 almost 200 million acres of the world's primary forests have been destroyed—and every year many more acres of these already rare ecosystems are being lost.

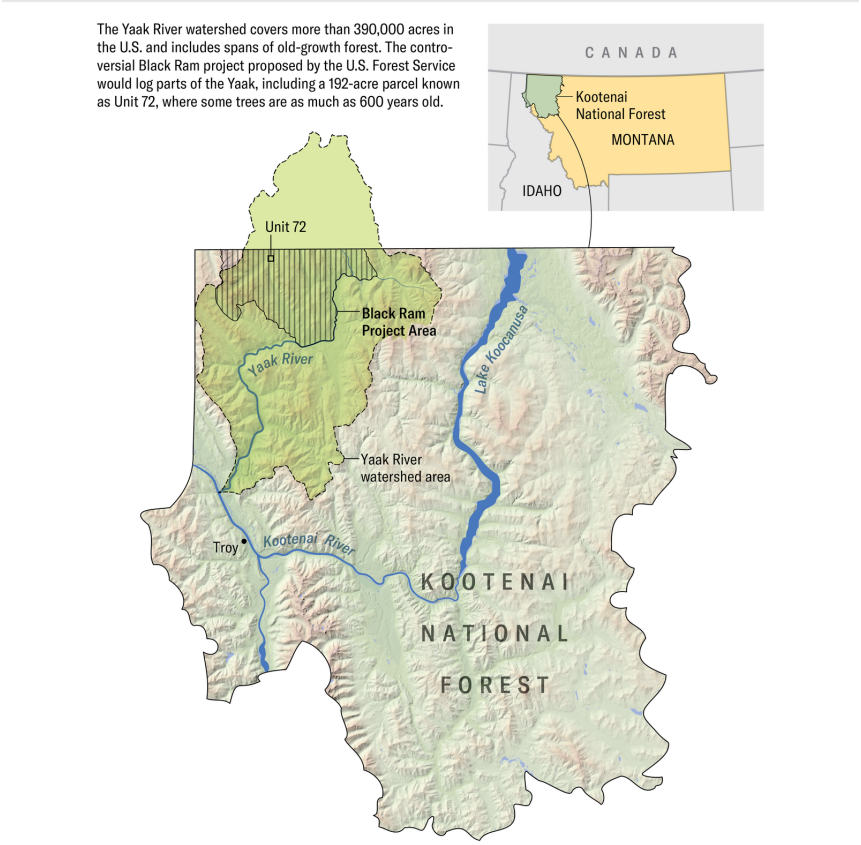
DellaSala has studied the biodiversity attributes and climate benefits of mature and old-growth forests around the world. He visited Unit 72 at the council's request after the USFS proposed the Black Ram project, to evaluate whether the unit was indeed old growth. "I can give you all kinds of stats and measurements, but it came down to this," he says. "If it looks like old growth, it smells like old growth and it feels like old growth, it must be old growth. And Unit 72 sure was."

The diversity impressed him. "There were big trees, small trees, midsize canopy trees. It was the perfect structure for an older

forest.”

The day he went to the stand, DellaSala says, was beautiful “but hotter than hell. I remember just sweating bullets as we were walking along the road and through the clear-cuts. Then we entered the stand, and immediately it was like being in outdoor air-conditioning. The cooling effect of that stand—it really caught my attention.” Trees were covered with lichens and all kinds of bright mosses, “the diversity of plants that I would expect to see in an older forest,” he says. “And all that carbon tied up for centuries in the big trees and in the soils. Unit 72 was an easy write-up for me.”

The USFS approved the Black Ram project in June 2022. The Yaak Valley Forest Council sued the federal government in response, partnering with the Center for Biological Diversity and WildEarth Guardians. In January 2023 the Native Ecosystems Council and the Alliance for the Wild Rockies also filed a joint complaint. The plaintiffs asserted that the USFS violated the National Forest Management Act and the National Environmental Policy Act and did not adequately consider the project’s impacts on the region’s grizzly bears, a threatened species under the Endangered Species Act. They criticized the USFS for failing to prepare a full environmental impact statement, and they argued that the government didn’t consider the climate impact of logging the Yaak’s old-growth forests.



Credit: Dolly Holmes

Seven months later, on August 17, 2023, U.S. District Judge Donald Molloy blocked the agencies' approval of Black Ram, largely agreeing with the plaintiffs' claims. Every year temperate forests in the U.S. absorb about 15 percent of the country's carbon emissions. Old-growth and mature forests are particularly effective. As a tree ages, its ability to sequester carbon increases, research has shown. Old-growth stands store 35 to 70 percent more carbon, including in the soils, than do logged stands. "Ultimately," Molloy wrote in his decision, "removing carbon from forests in the form of logging, even if the trees are going to grow back, will take decades to centuries to resequester. Put more simply, logging causes immediate carbon losses, while resequestration happens slowly over time, time the planet may not have."

Kristine Akland, Northern Rockies director and senior attorney for the Center for Biological Diversity, says the court ruling is precedent-setting. "This is the first time in the context of a timber sale that I'm aware of that a court has said that the Forest Service ...

has to take a hard look at what projects like this actually mean for carbon sequestration, for carbon emissions." Going forward, she notes, "for every single logging project, if not across the nation, then at least across Region One, the agency has to change its methods of analysis to include these questions." Region One comprises 25 million acres of public lands that the USFS manages in northern Idaho, Montana, North Dakota, and parts of South Dakota and Washington State.

Akland adds that logging projects that target mature forests, not just old-growth ones, should be evaluated similarly. "The way we increase old growth is to protect the trees that are almost there."

Other stakeholders in the Kootenai National Forest disagree with the court's ruling, including Julia Altemus, executive director of the Montana Wood Products Association. "To say that old-growth forests are the answer to climate change—that's not quite right," she says. "They're part of the solution. They're certainly important." Her group and others argue that trees lose carbon once they hit a certain age. But DellaSala says there is "no argument in the scientific community about sequestration." Carbon sequestration, he goes on, "reaches a dynamic equilibrium in old-growth stands over time." But it doesn't decline. Individual trees, he says, "don't stop accumulating carbon.... The larger the tree, the more surface area, the more carbon accumulates."

For now the Black Ram project is stalled, but the USFS could "bring it back at any time," Bass says, perhaps by changing the project's plans a bit. Dan Hottle, press officer for USFSRegion One, says the agency is "still evaluating the court's decision and determining next steps." He also says that Unit 72 "does not meet the definition of 'old growth.'" In the meantime, Bass and the Yaak Valley Forest Council are working with a network of scientists and environmental groups toward a move they hope will offer Unit 72 permanent protection and serve as a model for other old-growth forests around the country and across the world. Their goal is to

have the forest designated as the nation's first "climate refuge," an area that remains relatively buffered from contemporary climate change over time and enables persistence of valued physical, ecological and sociocultural resources. In other words, Bass says, "it would be a sanctuary for wildlife and biodiversity and a tool for slowing climate change."

The goal is lofty, Bass recognizes, but not unachievable. "The Forest Service and the Fish and Wildlife Service haven't been shy about pursuing pilot or experimental projects," he says. The priority should be "that the carbon-storing potential of these ancient forests—particularly in the northern latitudes and particularly at Black Ram—be protected with maximum urgency." Moreover, "this forest doesn't need our help," Bass says. "It's a natural solution for addressing the climate crisis just as it is. It is fire-resilient just as it is. Instead of worrying about the world burning, we can help cool it—by leaving this forest, and others like it, just as it is."

A giant cedar binds the forest floor.
Credit: Chris Balboni

Leslie Caye, a member of the Kootenai, Yakama and Nez Perce nations, agrees. “It’s time to consider the concept of leaving things alone,” he says. “Let the forest be, without interference, without interruption.” Caye grew up on the Flathead Indian Reservation southeast of the Yaak and on the Yakama Reservation in Washington State. Today he develops Kootenai language and culture programming, as well as curricula for youth, on the Flathead reservation. The Yaak, he says, “is a part of our ancestral lands—lands that we lost, that were taken from us.” In times past,

he says, “my people would go up there by the thousands to the Yaak Valley, and they would sing for a couple of nights in a row. For generations two forms of ceremony took my people there: the summer drumming ceremony that was part of our Sun Dance and what you might call, in layman’s terms, the vision quest, which helped us understand how to live as a Kootenai person. Our holy lands, you might say, are up there in the Yaak, including in Unit 72.”

Caye says, “We want to be able to return to that place, and other sacred places, to practice our cultural lifeways.... This is part of the process of reclaiming our identity as Kootenai people—that rejuvenating religious force that is the underpinning of who we are. But if the forest is being logged, how can we return there to practice our ceremonies? This, too, needs to be a part of the conversation.”

Last October, Bass unveiled a new tool he hopes can help save Unit 72 and old-growth forests everywhere. It was a guitar crafted by a renowned luthier from a length of a spruce tree that fell when the USFS cut a logging road to the edge of Unit 72. The guitar made its debut at the inaugural Climate Aid concert, in Portland, Maine, with a young American singer-songwriter, Maggie Rogers, performing with it. Today Bass carries the guitar to festivals and concert halls, schools and libraries across the country, where musicians play it, advocating for the future of old-growth forests. At each event, Bass asks, “Can a guitar save a forest?”

The morning after I walk Unit 72 with Bass, I begin the 10-hour drive to my home in south-central Montana, following the Yaak River to Highway 2. Mist clings to the forests, and the mountains are shrouded in clouds. In Troy, the first town I encounter, wood-smoke drifts upward from chimneys, and apples hang heavy from neighborhood trees. I buy a cup of tea for the road, and then I backtrack to the Troy Ranger Station just north of town to pick up some maps, including one of the Black Ram project. The

receptionist is warm, friendly and generous, giving me a poster of pollinators as I leave after I commented on how beautiful it was.

I'm about a mile down the road when I see a moose step out of the thick forest. A logging truck coming the opposite way slows to a stop to let it cross, and so do I, but the moose turns and lopes back into the trees. I think of *The Book of Yaak* and a question Bass poses in it: "Settling in [to the Yaak] was not so much work and effort as it was relief, pleasure and peace. Does such a place exist for everyone? How many places are left in the world—what diversity of them still exists—and for that diversity, what tolerance, and what affinity?... What is the value of a place?"

It strikes me that the future of the Yaak's old-growth forests, maybe the future of old-growth forests everywhere, might just hang on that question.

Alexis Marie Adams lives at the edge of the Greater Yellowstone Ecosystem in Montana and on the southern Peloponnese Peninsula in Greece. Her work has been published by *National Geographic*, *the Guardian*, *Orion Magazine*, and others.

Animals

- **Hummingbirds Control Their Flight with a Newfound Mechanism**
  When zooming forward, hummingbirds rely on a unique internal “cruise control”

Hummingbirds Control Their Flight with a Newfound Mechanism

When zooming forward, hummingbirds rely on a unique internal "cruise control"

By Ellyn Lapointe

Hummingbird hovering in flight.
Kenneth Lui/Getty Images

Hummingbirds are the Olympic gymnasts of the avian world. They zip around at remarkable speeds, hover in place and fly in all directions, including backward and while upside down. They can even perform flips.

To achieve such agility, hummingbirds use distinct modes of visual processing to control different types of flight, researchers report in the *Proceedings of the Royal Society B*. In particular, the scientists uncovered a seemingly unique mode that guides hummingbirds' speed when they are flying forward.

The findings come from an analysis of more than 3,500 hummingbird flights inside a 12-foot-long tunnel with a perch at

one end and a feeder at the other. Moving patterns projected on the tunnel walls manipulated the hummingbirds' sense of optic flow—the perceived motion of surroundings while traveling through the world. The speed of that motion, called pattern velocity, is a key visual cue that many animals use to adjust their own speed and position as they move.

The researchers expected that if the hummingbirds were using pattern velocity cues to control their forward flight speed, they would see the birds speed or slow in sync with vertical stripes projected on the side walls. But instead "it seemed more the case that they have their own internal speedometer or internal gauge" for forward flight, says study co-author Vikram Baliga, a comparative physiologist at the University of British Columbia.

Any movement that defied the hummingbirds' expectations of how their surroundings should change slowed the birds down—even vertical stripes moving toward the feeder, which the researchers expected would make them speed up. When hovering or moving up or down, however, the birds based their motor commands on the projected patterns they saw.

The ability to switch between these different flight modes underlies a hummingbird's singular agility, says study co-author Doug Altshuler, a zoologist at the University of British Columbia specializing in complex locomotion. Hummingbird brains have

evolved to make rapid transitions from visual signals to motor outputs. “You watch them fly through the forest, and they’re dodging trees and moving branches in the wind—and each other,” he says. “They are adept at taking in lots of complicated visual information and making a robust and safe flight plan out of that.”

Further research will delve into the ways the birds predict how their movement will affect the flow of scenery around them. Understanding that could help engineers improve drone technology, says Bo Cheng, a mechanical engineer at Pennsylvania State University. “Can we develop a mathematical model for this prediction of optical flow?” Cheng asks. If so, “that could be very useful for drones.”

Ellyn Lapointe is a New York City–based science journalist with a special interest in covering the life sciences.

Artificial Intelligence

- **New Insights from AI, Strange Metals and Parents of LGBTQ Kids**
  AI has deciphered ancient texts, learned new math and provided new ideas about human consciousness

New Insights from AI, Strange Metals and Parents of LGBTQ Kids

AI has deciphered ancient texts, learned new math and provided new ideas about human consciousness

By Laura Helmuth

Scientific American, April 2024

Artificial intelligence is finally starting to live up to the second half of its name. You've probably heard a lot of buzz about large language models lately—the text-producing AIs that can spit out fluent essays based on the books and articles and other data they've been trained on. They may sound smart, but on closer inspection, they are full of biases and make things up (you may know someone who does something similar). In this issue, we present some of the more interesting new insights from AI research.

The eruption of Mount Vesuvius in C.E. 79 destroyed the Roman towns of Pompeii and Herculaneum, but it didn't quite destroy a library full of scrolls, which was found in 1709. Scholars tried to

unroll and read the charred papyrus, only to destroy the scrolls in the process. Writer Tomas Weber reports on a contest to use AI to decipher the ancient Greek text. The artifacts posed problems that only machine learning could solve. Now researchers have used AI to rediscover a long-lost philosophical passage about pleasure.

The quest to make AI even more intelligent is advancing our understanding of human intelligence, as author and *Scientific American* contributing editor George Musser tells us. According to one theory, consciousness is what makes sense of inputs and analyses from various brain regions, a kind of workspace for solving problems. As AI advances, it is using and testing theories about how the different parts of the mind collaborate.

AIs are now capable of solving geometry problems at the level of gold-medal Olympiad contestants, as physicist and writer Manon Bischoff explains. And large language models trained on religious texts are helping scholars translate and comprehend such works—but as science journalist Webb Wright discusses, some theologians are worried about the implications. No word yet on whether an AI will create nine billion words for “god,” as happens in an Arthur C. Clarke short story, and end the universe.

The best parents learn from their children—learn to be stronger for their sake and more compassionate, learn to appreciate the world in new ways. I’m inspired by parents who overcome their own

expectations when they find out their child is gay or transgender or otherwise doesn't fit in traditional roles. As more anti-LGBTQ laws are introduced and passed in the U.S., many of these parents are fighting for their children's rights, education and basic health care. Author Marla Broadfoot shares how parents are learning to support their kids and one another.

As physicist Douglas Natelson points out, human technology has advanced through the use of metals since the Bronze Age. Yet we still don't fully grasp their properties. In a new class of metals called strange metals, electrons behave as swarms rather than individual particles. Natelson describes how scientists are poking and prodding these metals in creative ways, hoping to understand not just these materials but all metals and even get insights into physical interactions at the event horizons around black holes. Diagrams from *Scientific American* senior graphics editor Jen Christiansen are interspersed throughout the text of the story to help you visualize and enjoy this research.

One of the few remaining old-growth forests in the continental U.S. has existed for thousands of years, and we hope it will exist a thousand more. The Yaak, in northwestern Montana and upper Idaho, spreading into Canada, is a rich rainforest, and parts of it have never been logged. A Trump-era proposal to allow logging in the Yaak has been blocked in court for now but not abandoned. Writer Alexis Marie Adams takes us on a tour of the sights and sounds of this rare and majestic forest.

Laura Helmuth is editor in chief of *Scientific American*. She previously worked as an editor for the *Washington Post, National Geographic, Slate, Smithsonian* and *Science*. She is a former president of the National Association of Science Writers. She is currently a member of the National Academies of Sciences, Engineering, and Medicine's standing committee on advancing science communication and an advisory board member for SciLine and The Transmitter. She has a Ph.D. in cognitive neuroscience from the University of California, Berkeley. She recently won a Friend of Darwin Award from the National Center for Science Education. Follow her on Bluesky @laurahelmuth.bsky.social

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ai-strange-metals-and-parents-of-lgbtq-kids

Arts

- **Contributors to Scientific American's April 2024 Issue**
  Writers, artists, photographers and researchers share the stories behind the stories
- **Poem: 'SnapShot, 1968'**
  Science in meter and verse

Contributors to *Scientific American*'s April 2024 Issue

Writers, artists, photographers and researchers share the stories behind the stories

By Allison Parshall

Gioncarlo Valentine

Gioncarlo Valentine
Families Under Attack

For this issue's story by journalist Marla Broadfoot on families threatened by anti-LGBTQ legislation, photographer Gioncarlo Valentine (*above*) took a drive down the East Coast from Massachusetts to Florida. "I do a lot of road trips," he says. "I think

I enjoy processing [these experiences] in between the stops.” In the car, he and his assistant read Broadfoot’s article aloud as they prepared to meet and photograph the people who had shared their stories. The families were “really remarkable and kind”—the mother of the first family they met welcomed them with a pot pie and has remained in touch. “Nobody was just there to be photographed. Everybody talked; everybody told us their stories.”

It was a heavy, emotional process, says Valentine, a queer photographer and writer based between New York City and Philadelphia. For his work, he draws on experiences from his previous career—Valentine served as a case manager for seven years, inspired by the social workers who changed his life when he was in foster care or chronically unhoused. “Holding people’s stories is the foundation of my work as an artist,” he says. “It’s difficult to make images about really somber and sad stories when you are personally indicted in them,” but it’s necessary work in the face of such injustice.

Tomas Weber
The Race to Decode an Ancient Scroll

When Tomas Weber first heard about a competition to use artificial intelligence to decipher scrolls from the ancient Roman town of Herculaneum near Pompeii, “my alarm bells started ringing that this could be a cool story,” he says. Weber, a London-based

journalist who unspooled the competition's stunning results for this issue's special report on AI, is especially interested in people who have been captivated by powerful technology. "I've always had really deep but fleeting interests," he says, making long-form journalism the perfect job for him. "I just sort of plunge myself into these worlds."

With all the fear and fervor surrounding the future of AI and humanity, there's something particularly poignant about using these technologies to decipher text from an extinct civilization and learn about "a society that's already succumbed to disaster in the form of a volcano," he says.

And even beyond that, these attempts to uncover literature from a long-lost civilization are "a great, almost kind of meta subject for a writer," Weber says, whose work will one day surely be lost to time.

Alexis Marie Adams
Last Stand

At a party in Missoula, Mont., last year, one of Alexis Marie Adams's friends whipped out an eye-catching guitar. It had been fashioned from an old-growth spruce tree, and "I was really quite taken by it," Adams says. The guitar led her to Montana's Yaak region, and she reports on threats to its irreplaceable ecosystem in her feature story on old-growth forests. Adams was already well acquainted with these majestic biomes; as a child, she lived on the edge of redwood forests in California. "I would spend a lot of time there exploring alone. I think that left an imprint."

Growing up, Adams also lived in Michigan, England, Greece and Montana. Her mother is adventurous and "just wanted to have these experiences and share them with me," Adams says. She now splits her time between two small towns, one on the coast of Greece's Peloponnese Peninsula and the other in south-central Montana. In

these quiet, rural places, resource extraction is “a big part of the culture and the economy,” she says.

Communities from the Balkans to the Amazon to the Yaak have long faced difficult questions of how to preserve these ancient forests. “This is a really universal story,” Adams says.

Matthew Twombly
The Race to Decode an Ancient Scroll

As a child, Matthew Twombly painstakingly copied panels from comic books into his sketchbook. Today much of his work as a Pennsylvania-based illustrator and graphic designer still echoes that sequential style of visual storytelling. For this issue, Twombly made an infographic to explain how AI has helped researchers decipher charred ancient scrolls. Although he has spent his career translating complex science into illustrations, visualizing the inner workings of AI poses unique challenges. “No one really knows how it works, just that it does,” he says. “It’s this foreign concept to wrap your head around.”

There’s a lot of hype around the dangers and promises of AI, but there are also serious and immediate questions about protecting people’s copyright and likenesses, Twombly says. “We’ve kind of just unleashed this thing and hoped for the best.”

Allison Parshall is an associate news editor at *Scientific American* who often covers biology, health, technology and physics. She edits the magazine's Contributors column and weekly online Science Quizzes. As a multimedia journalist, Parshall contributes to *Scientific American*'s podcast *Science Quickly*. Her work includes a three-part miniseries on music-making artificial intelligence. Her work has also appeared in *Quanta Magazine* and Inverse. Parshall graduated from New York University's Arthur L. Carter Journalism Institute with a master's degree in science, health and environmental reporting. She has a bachelor's degree in psychology from Georgetown University. Follow Parshall on X (formerly Twitter) @parshallison

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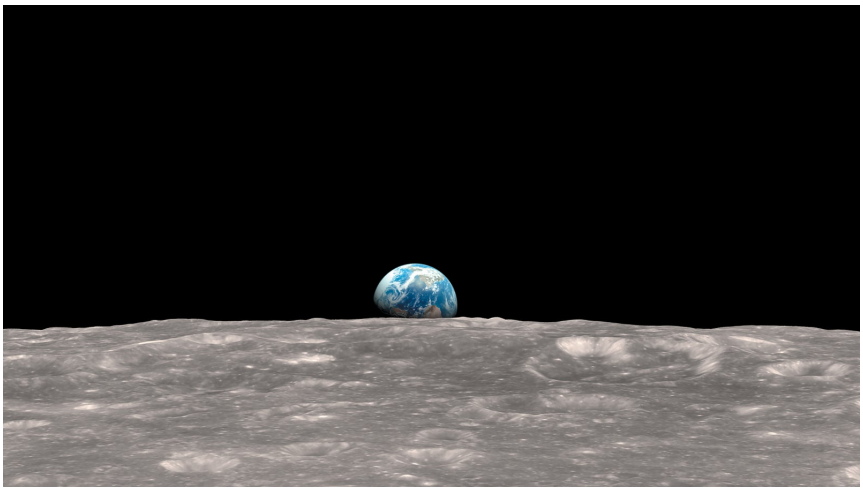
Poem: ‘SnapShot, 1968’

Science in meter and verse

By Gregory Bell



NASA/Goddard Space Flight Center

Edited by Dava Sobel

From the bright backside of the moon
(never before seen by living eyes
and startled to be so violated)
William Anders, born in Hong Kong
Boy Scout, raised in California
One Holy Catholic & Apostolic pilot
trained to excel floats tumbles shifts
inside Apollo 8

With a Master of Science in nuclear engineering
the astronaut, authority in dosimetry
radiation effects and environmental control
is in charge of taking lunar pictures *click*
Crater Giordano Bruno *click* *Mare Smythii*
Apollo’s shadow crawls below lengthens
points: *Oh, my God!* *Look at that ...*

There's the Earth coming up.
Wow!

On supporting science journalism

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For slow as an opening flower
Up up above the barren moonscape
afloat in the stark black void
she silent rises into view
of three men sent to conquer space
and chart the craters of the moon
who now gasp in awe
of newfound recognition:

This planetary marbled cat's-eye
oceanic atmospheric fragile
this blue pearl set in unforgiving sky
smack in the impossible Goldilocks zone
this mother to 3½ billion people and growing
to 9 million species and dwindling
flecked with oceans and clouds
held in by atmosphere as thin
in proportion as the skin to the apple
alone in all the known universe
a living planet
click-snap
is home
EarthRise!

Gregory Bell, poet, playwright and actor, is the recipient of the 2019 Steve Kowit Poetry Prize and a 2023 Helen Schaible International Sonnet Contest prize. His hybrid poetry collection, *Looking for Will: My Bardic Quest with Shakespeare*, was published by Ion Drive in 2015.

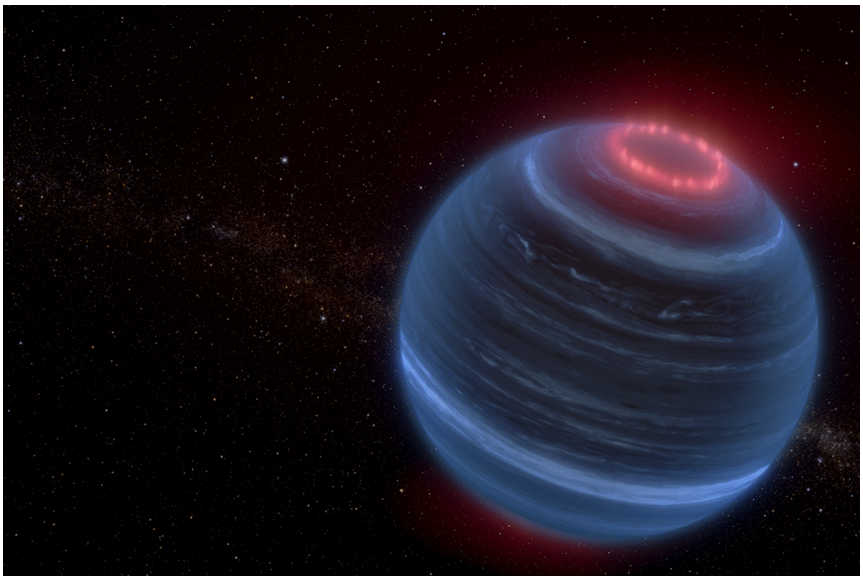
Astronomy

- **This Nearby Brown Dwarf May Have Auroras--And a Moon, Too**
  Glowing methane on a brown dwarf dozens of light-years from Earth may signal the presence of a large lunar companion

This Nearby Brown Dwarf May Have Auroras—And a Moon, Too

Glowing methane on a brown dwarf dozens of light-years from Earth may signal the presence of a large lunar companion

By Phil Plait



An artist's concept of the cold brown dwarf W1935.
NASA, ESA, CSA, Leah Hustak (STScI)

At a recent annual meeting of the American Astronomical Society (AAS)—the largest organization of professional astronomers in the country—many cosmic objects got their moment to shine.

In the case of brown dwarfs, though, that shine is pretty faint.

Brown dwarfs exist in a kind of netherworld category between planets and stars. They're massive enough that the pressure in their core is sufficient to fuse deuterium—an isotope of hydrogen—but not massive enough to fuse normal hydrogen, the self-sustaining process that defines a proper star. This mass range is from about 13 Jupiters up to about 75 times that gas giant's heft (or about 0.075 times the mass of the sun).

They also generate heat through gravitational contraction, and some, near the tippy top of the mass scale, also fuse lithium. But all these processes are fleeting, leaving brown dwarfs relatively inert. Because of this, they are sometimes referred to as failed stars, a moniker that I think is blatantly unfair. Who are we to judge? Maybe brown dwarfs are really just overachieving planets.

But because the fusion process is ephemeral, shortly after brown dwarfs form, they simply cool, and over time they fade. This means that they're extremely faint in visible light and can be completely invisible to optical telescopes, even when they're quite close to Earth. The first brown dwarf that was discovered, Teide-1, located in the nearby Pleiades star cluster, wasn't even confirmed until 1995. The good news is that these objects retain much of the leftover heat from their formation, so they emit an enduring infrared glow, making them far easier to spot in those wavelengths.

Still, nearly three decades after that initial discovery, there's much that we don't know about brown dwarfs. There's still an aura of mystery about them—in one case that was announced at the AAS meeting, a quite literal aura.

CWISEP J193518.59-154620.3—let's call it W1935 for short because that's what astronomers do—is a brown dwarf located in the constellation Sagittarius. It's very cold, as these things go: it's somewhere around 200 degrees Celsius, making it incredibly faint.

It wasn't discovered until 2019 despite being only about 47 light-years from Earth. That's extremely close on a galactic scale, practically on our doorstep.

Astronomers recently used the James Webb Space Telescope (JWST) to observe W1935 as part of a program to better understand the composition, structure and atmospheres of cold brown dwarfs. They separated the object's light into individual colors to form its spectrum, which can be used to show the presence and abundance of different molecules such as water and carbon dioxide.

The spectrum revealed a surprise, though. Usually gaseous atmospheric methane in a brown dwarf absorbs the infrared light that comes up from below, so there's a dip in brightness at certain spectral wavelengths. What the astronomers saw was just the opposite: instead of absorbing infrared light, the methane was emitting light. That means there must be something pumping energy into the methane molecules in W1935's atmosphere.

No peer-reviewed paper has yet been published on the research, but this spectral surprise raises some interesting questions. This brown dwarf is far too cold for its ambient temperature to be the energy source exciting the methane. Although it's possible that some internal processes are to blame, a far more likely explanation is that W1935 has an aurora, according to the astronomers who collected the data.

That's a big surprise! On Earth, auroras occur when the sun's solar wind of subatomic particles is swept up by our planet's magnetic field. The particles are funneled down into our atmosphere, where they slam into its gaseous atoms and molecules, making them light up like a literal neon sign.

Brown dwarfs can have strong magnetic fields, so that certainly seems possible. The problem is W1935 is a cosmic loner; there are

no stars near it that could feed it particles to make an aurora.

There's another possibility, though, and it's pretty intriguing. Jupiter has an aurora that's fueled by the solar wind and also sparked by three of its moons: Io, Europa and Ganymede. In the case of the tectonically hyperactive Io, for example, sulfur that it volcanically spews out into space interacts with Jupiter's magnetic field, creating an aurora.

Could something similar be occurring with W1935? If it has a moon or, more excitingly, even a planetary-mass body orbiting it, then volcanic activity on that companion could be driving the aurora. The influx of particles would be captured by the brown dwarf's magnetic field and flow down into the atmosphere, exciting the methane molecules and causing them to glow. Even though it's close to us, cosmically speaking, W1935 is still too far and faint for us to see any orbiting companions. But it's possible that such a body could be indirectly detected. For example, just as we see with Jupiter's moon-induced aurora, W1935's aurora could cyclically wax and wane in sync with a companion's orbital period. Discerning that pattern would probably be extraordinarily difficult, but in theory it could be possible.

Auroras have been detected around brown dwarfs before but never with one as cold as W1935. This discovery could lead to a better understanding of the behavior of brown dwarfs, especially ones with strong magnetic fields. And, who knows, maybe it could uncover a serendipitous planet or moon, too.

In general, nature tends to make few big objects and lots of little ones; for example, high-mass stars are rare, and lower-mass ones such as red dwarfs are common. If this rule extends to objects that are even more diminutive, brown dwarfs may be the most ubiquitous substellar objects in the universe. We've had nearly 30 years of observations showing just how interesting they are, and

still they manage to surprise us. Clearly, their time to shine is just beginning.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

Phil Plait is a professional astronomer and science communicator in Virginia. He writes the *Bad Astronomy Newsletter*. Follow him online.

Behavior

- **Why Some People Choose Not to Know**
  Altruists seek to understand how their actions will affect others—while willful ignorance can free people to act selfishly

Why Some People Choose Not to Know

Altruists seek to understand how their actions will affect others—while willful ignorance can free people to act selfishly

By Linh Vu & Margarita Leib

CSA Images/Getty Images

Willful ignorance abounds in daily life. People regularly look the other way rather than examining the consequences of their actions. Despite the plethora of scientific evidence for climate change, for instance, many people still avoid engaging with facts about global warming. They don't always want to know about the harsh living conditions of farm animals. And consumers often put aside ethical concerns about how the products they purchase were sourced.

As behavioral scientists, we wanted to understand just how prevalent willful ignorance is—as well as why people engage in it. Together with our colleagues, we pooled data from multiple research projects that collectively involved more than 6,000 individuals. We discovered that willful ignorance is common and harmful, with 40 percent of people choosing "not to know" the consequences of their actions to free themselves of guilt while

maximizing their own gains. But we also found that about 40 percent of people are altruistic: rather than avoiding information about the consequences of their actions, they seek it out to increase the benefits to others.

In our analysis, we used data from 22 previously published studies on willful ignorance. This approach gave us a much larger, more comprehensive look at this phenomenon than in past research. Although the specific experiments varied, most involved putting participants into pairs. People took part in the study either online or in person in a laboratory. Regardless of the setup, subjects did not interact and remained anonymous to one another. The researchers, meanwhile, knew how many people made a certain decision but could not pinpoint who chose what.

In the experiments, researchers asked one member of each pair to choose between two options. The selection would determine the earnings for both partners. These decisions were made in one of two settings. In the transparent setting, decision-makers had information about how their choice would affect themselves and their partner. In an ambiguous setting, decision-makers knew how their choice would matter for themselves but not for their teammate —although they could request that insight.

For example, participants in several studies had to decide between $5 and $6 payments. In the transparent setting, they knew that if

they chose $5 for themselves, their partner would also receive $5. If, however, they chose $6 for themselves, their partner would receive only $1.

In the ambiguous setting, the payout for partners worked differently. This time there were two possible scenarios. In one, if the decision-maker selected $6 for themselves, their partner would receive $1, and if the decision-maker chose $5, their partner would receive $5 (just as in the transparent case). But in a second scenario, the decision-maker could pick $6, and their partner would receive $5, or the decision-maker could select $5, and their partner would receive $1.

The decision-makers knew these two systems existed and understood how to receive a higher payout for themselves—but they were not initially aware of which scenario they were in. Interestingly, the decision-makers had the opportunity to resolve that ambiguity: by clicking a button, they could learn which payout scheme would apply to their decision. This option to learn more offered scientists a way of assessing willful ignorance.

Across all studies, we found that when participants were told the consequences of their choices—the transparent setting—the majority (55 percent) chose the altruistic option. That is, they gave up a part of their earnings to share equally with their partner. The remaining 45 percent knowingly kept a bigger payout at a cost to their partner.

In the ambiguous setting, however, 40 percent of participants chose to remain ignorant. Not knowing freed them to be selfish: 60 percent of people in the ignorant group chose a higher personal payout in scenarios where this choice came at the expense of their partner. Among those who requested more information, 36 percent knowingly kept a higher payout at a cost to their partner.

That means the overall balance tipped toward selfishness when participants had the option to avoid information. Only 39 percent of people in the ambiguous setting made the choice that ultimately benefited their partner—a significant drop from 55 percent in the transparent condition.

But how do we know whether ignorance in the ambiguous setting was *willful*? Could it be that some people avoided information unintentionally? To understand this point, we conducted a second analysis focused on what motivates people to seek information.

In this analysis, we looked at how people who *obtained* additional information behaved in comparison with those who were given information. We found that people who chose to receive information in the ambiguous setting were seven percentage points more likely to make the altruistic choice than were people in the transparent setting. In other words, our analyses identified some truly altruistic actors: those who sought information out and then made a decision that benefited their partner, even at a cost to themselves. That means information seeking is at least partially motivated by the desire to do right. By the same token, the finding also suggests choosing ignorance has value for people who want an excuse to be selfish.

We cannot rule out that some failed to click the button for more information unintentionally. But if confusion, laziness or even indifference was the *only* driver of ignorance, we would not have observed any real difference in our comparison. We found that seeking information was linked to a clear motivation: these truly altruistic individuals wanted to benefit their partner. So we concluded that conversely, ignorance is at least partially driven by the desire to shield oneself from one’s own judgment.

Our work suggests that sometimes people engage in altruistic behaviors because they feel pressure to do what is expected of them. When the consequences of choices are made clear, people

may feel obliged to make a small sacrifice and be generous to others. But when given a chance, they may want to ignore the consequences of their actions. Ignorance shields people from knowing how their actions harm others and makes them feel less like a bad person.

Our findings hint at ways to combat willful ignorance. In the studies we analyzed, decision-making occurred within a moral framing: you could benefit yourself at the expense of your partner. This presentation is fertile ground for willful ignorance because it poses a threat to one's self-image, heightening the sense that—if you know what's really going on—you will have to make harder choices to be a good person.

If we can avoid putting a strong moral emphasis on decisions, it may make people feel less threatened and, as a result, be less willfully ignorant. Other research groups have found promising ways to do this. For instance, we can present choices in ways that highlight ethical options first, such as making vegetarian menus the default, while still allowing people to opt for meat, as part of an effort to promote sustainable food choices. Or we could encourage people to think more positively about good deeds rather than guilt-trip them for what they have failed to do. Highlighting recent global achievements, such as healing the ozone layer, for instance, can inspire people to keep up the good work rather than feeling like the battle is lost and that the situation is all gloom and doom.

In short, we can encourage one another and ourselves toward more selfless and generous actions.

Are you a scientist who specializes in neuroscience, cognitive science or psychology? And have you read a recent peer-reviewed paper that you would like to write about for Mind Matters? Please send suggestions to Scientific American's *Mind Matters editor Daisy Yuhas at pitchmindmatters@gmail.com*.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

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Margarita Leib is an assistant professor at Tilburg University in the Netherlands, where she studies ethical decision-making.

Book Reviews

- ## How to Grieve Our Changing Planet
  A new book on the perils of human exceptionalism
- ## How the Strange Relationship between Chickens and Humans Shaped Our World
  Chicken takeovers, the missing histories of silk, a dazzling memoir of gravity, and more books out now

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How to Grieve Our Changing Planet

A new book on the perils of human exceptionalism

By Megan Mayhew-Bergman

Jason Holley

NONFICTION

We Loved It All: A Memory of Life
by Lydia Millet.
W.W. Norton, 2024 ($27.99)

“In the beginning,” Lydia Millet writes at the start of her latest book, “we gave names to every creature that we found ... home was

a garden, then—a garden in the wild." This opening casts a moving spell that remains with the reader through three sections of potent vignettes that blend personal stories, ecology and history. Terry Tempest Williams called it a "transformative anti-memoir," a fitting description for a book about loss on a scale we can hardly fathom —grief for an Eden we glimpsed and ruined, at great cost to ourselves and other species.

In 2012 Millet published an op-ed in the New York Times about the toys we play with as children and what will happen when human activity causes the extinction of our "youthful menagerie" of polar bears, elephants and tigers. The op-ed feels like a precursor to *We Loved It All*—where does the childhood love of nature go? How do we go on to tolerate the impoverishment of existence as nature degrades in front of our eyes and species are lost? Can culture and selfhood reshape themselves in the absence of all this beauty?

Millet's philosophical and eulogistic tone echoes the past tense of the title. "Our old home is gone," she writes, before making a case for remembering and honoring the co-evolution of the human animal and other species. She urges respect for the staggering interconnectedness of existence. Millet—writing with all the narrative talent of a Pulitzer Prize–nominated novelist—suggests we are in many ways already haunted by the sins of attempting to sever this connection, even if we preserve the remaining wonders.

In an era of literature where it has become fashionable to make climate change a plot point, it is refreshing to read a book that is both emphatically beautiful at the line level and deeply insightful at an ecological level. Millet has spent decades immersed in environmental work with the Center for Biological Diversity in Arizona. We benefit from her experiences: anecdotes about heat-stricken flying foxes, passenger pigeons, ibex, pit ponies and predacious snails ground the work in earthly, high-stakes reality.

To explore daunting and existential questions about the "extraordinary experience of being, even within a so-called ordinary life," this anti-memoir does get deeply personal. We hear tales about Millet's emotionally restrained father on his deathbed, her ex-husband rescuing people injured in an explosion, her life as a parent, her grandfather abroad among prolific huntsmen, and her work experiences copyediting for *Hustler* magazine. These stories remind us of our own awe, suffering and generational complicity in the destruction of the natural world—the frogs we have stepped on, the atrocities we've witnessed, the resources we've used.

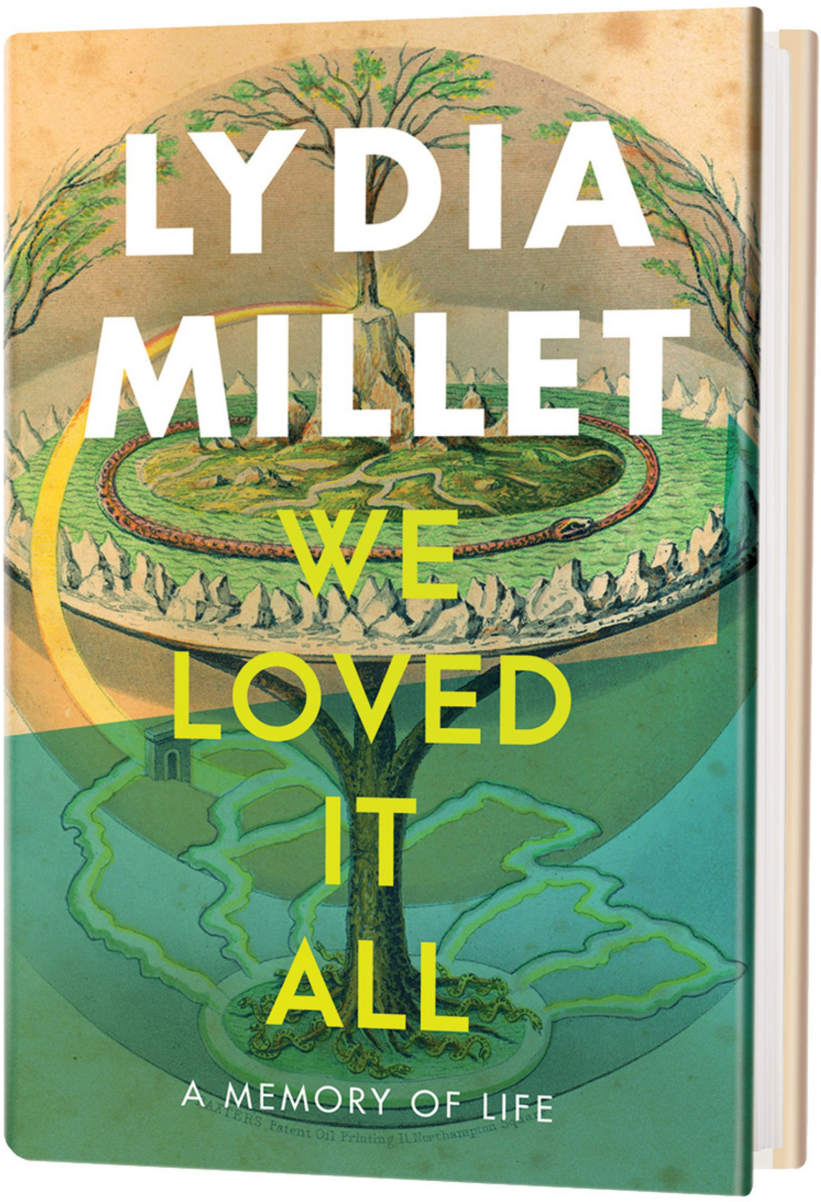
Millet enters her most profound terrain when questioning human exceptionalism, which she likens to a troubling form of supremacy. She notes the heresy of evoking anthropomorphism and imagining the minds of plants—and our likely underappreciation of animal cognition and intelligence: "What do the others know that we never will? What do they see, hear, and feel that we never have?" In broaching the question of rights for nonhuman animals she asks who or what deserves a life without suffering.

We Loved It All maintains a concern with language and story throughout. "Language was made of animals. As was art," Millet writes, reflecting on the animal-shaped glyphs that later became human language. She writes movingly of the new terms we have invented to capture the nuances of the Anthropocene—such as "endling" (the last of a species) and "species loneliness." In doing so, she also seems to question the idea of literacy—not just in its

conventional literary sense but with respect to scientific and cultural literacy. Our species may lack the ability to recognize the magnitude of what human action has done to the planet and to reckon with the consequences.

The next step is questioning the stories—and even lies—we have told ourselves to justify human behavior and its gruesome impact on other species, namely, “our monomythic story of progress and triumph—the superstory that captures us all.” Millet believes we ultimately will find ourselves “surprised into speechlessness, standing among the ruins. Led into a dead end by a story that proved untrue.”

These are, obviously, not tales of easy wonder. Yet *We Loved It All* is run through with wonder, even when it’s painful. Millet’s beautiful prose helps us face, and process, the gut-twisting experience of watching human error unfold.



Megan Mayhew-Bergman is an award-winning journalist, essayist and critic and serves as director of the Bread Loaf Environmental Writers' Conference at Middlebury College. She is author of three books, most recently, *How Strange a Season* (Scribner, 2022).

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How the Strange Relationship between Chickens and Humans Shaped Our World

Chicken takeovers, the missing histories of silk, a dazzling memoir of gravity, and more books out now

By Tove Danovich

Serhii Yushkov/Getty Images

NONFICTION

Fowl Play: A History of Chicken from Dinosaur to Dinner Plate
by Sally Coulthard.
Apollo 2024 ($27.99)

As you're reading this, there are more than 20 billion chickens alive on the planet. They live absolutely everywhere—except for Antarctica—playing important roles not just in our kitchens but in our cultures. In this extremely well-researched book, author Sally Coulthard traces the arc of the chicken from its ancestors among the dinosaurs through domestication by humans.

Refreshingly, *Fowl Play* doesn't repeat false claims from past chicken histories. Instead it offers stories about the way chickens have shaped the human world, including the strange effects that domestication has had on chickens and humans alike. Chickens invaded our cultures and our language: "Brooding" men, hot "chicks" and "cocky" youths are all part of our vocabulary. Folk magic and religion rely heavily on chickens and their eggs as both physical objects and symbols. Eggs have been viewed as metaphors for rebirth and as a "harbinger of doom." One particularly eye-opening section of the book traces the role of chickens in medicine. Not only were chicken eggs integral to vaccine development (they are still used for developing proteins and flu shots), but experiments on chickens (some quite bizarre) led to some of our earliest understanding of blood vessels and organ transplants.

For readers hoping to understand how the chicken got to be a species with such global dominance, *Fowl Play* is a welcome addition to the canon. Yet it's focused on what people have done to —or taken from—chickens more so than the story of the birds themselves. "Of all animals," Coulthard writes, chickens "perhaps best represent the strange and often contradictory way we humans treat other species." Occasional mentions of scientific studies on chicken behavior simply present the information; she doesn't go as far to suggest these findings imply that we should treat chickens as more than mere commodities.

Coulthard, who is a chicken keeper herself, does recognize the cost of our relationship with chickens from an ethical and environmental standpoint. One section explains why intensive chicken production is a major source of pollution and how widespread use of antibiotics for this production has been linked to the growing problem of antibiotic resistance. In *Fowl Play*, the contradiction in how we treat chickens isn't just an abstract ethical conundrum; it is one with real consequences for our health and the health of the planet.

IN BRIEF

The Beauty of Falling: A Life in Pursuit of Gravity
by Claudia de Rham.
Princeton University Press, 2024 ($27.95)

"What exactly is gravity?" is the question that drives Claudia de Rham's explorations of the puzzling, irresistible force that governs our universe. This part-memoir, part-textbook begins with a crash course in gravity's fundamental nature, from Newton and Galileo to black holes and dark energy. Eventually de Rham introduces her and her colleagues' groundbreaking theory of "massive gravity," bringing readers to the cusp of a scientific shift beyond Einstein's long-standing theory of general relativity. The best moments,

though, are when de Rham recounts her own interfaces with gravity —as a scuba diver, pilot, aspiring astronaut and theoretical physicist—giving this force an alluring personality. —*Lucy Tu*

Silk: A World History

by Aarathi Prasad.
William Morrow, 2024 ($32.50)

A silk garment is not a single object but a composite of thousands of individual silkworm cocoons; likewise, there is no single history of silk. Biologist and writer Aarathi Prasad unwinds tangled threads to weave one arc through China, India, Europe and South America. We learn about dogged early scientists who crossed oceans and amassed massive personal collections to better understand silk's biology and production. Fascinating facts abound: *Bombyx mori* is just one of a bevy of wild and domesticated silk-producing moths; "sea silk" can be isolated from a giant mollusk. Despite her efforts, Prasad readily asserts that many locals who shaped silk and its study "remain nameless"—their missing stories an unmendable hole. —*Maddie Bender*

The Limits: A Novel

by Nell Freudenberger.
Knopf, 2024 ($29)

When teenager Pia moves back to New York City to live with her father and pregnant stepmother, she struggles with friendships, family tensions and stifling COVID restrictions. She longs to return to the French Polynesian island of Mo'orea and to Raffi, an island native who assists with her mother's research on deepwater coral. Pia's infatuation with Raffi prompts her to join his struggle against the continued exploitation and degradation of the South Pacific, inspiring her to take ever bigger risks to show her devotion. Fiction writer Nell Freudenberger masterfully captures her characters' divergent perspectives and complex ties as they encounter extreme circumstances. —*Dana Dunham*

Tove Danovich is author of *Under the Henfluence: Inside the World of Backyard Chickens and the People Who Love Them (*Agate, 2023). She lives in Portland, Ore.

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Conservation

- **Which Lost Species May be Found Again? Huge Study Reveals Clues**
  There are 856 mammal, bird, amphibian and reptile species currently missing—but researchers continue to search
- **Pollinators Flock to Flower-Filled Solar Panel Fields**
  Solar farms seeded with wildflowers can boost pollinator populations

Which Lost Species May be Found Again? Huge Study Reveals Clues

There are 856 mammal, bird, amphibian and reptile species currently missing—but researchers continue to search

By Daniel Shailer

Rare flat-headed cats were declared “lost” before the species was rediscovered in 1995.

Gison Morib was lying in bed, sick from exhaustion after a month-long jungle expedition, when his phone buzzed, revealing a black-and-white photograph of a long-nosed, fuzzy animal. Morib ran outside, jumped on his motorbike and sped through the city of Sentani in Indonesian New Guinea to his colleagues’ expedition and research base, where he broke down in tears. “I cannot believe we found it,” was all he could say, over and over. After three years of study and four weeks trekking through the island’s remote Cyclops Mountains—and after one leech attached itself to Morib’s eyeball—the team had finally captured, via camera trap, the first recorded sighting in more than 60 years of Attenborough’s long-beaked echidna. “Even now I can’t describe the feeling when we

got it," says Morib, a biology undergraduate student at the local Cenderawasih University. "I cannot describe the goodness of God."

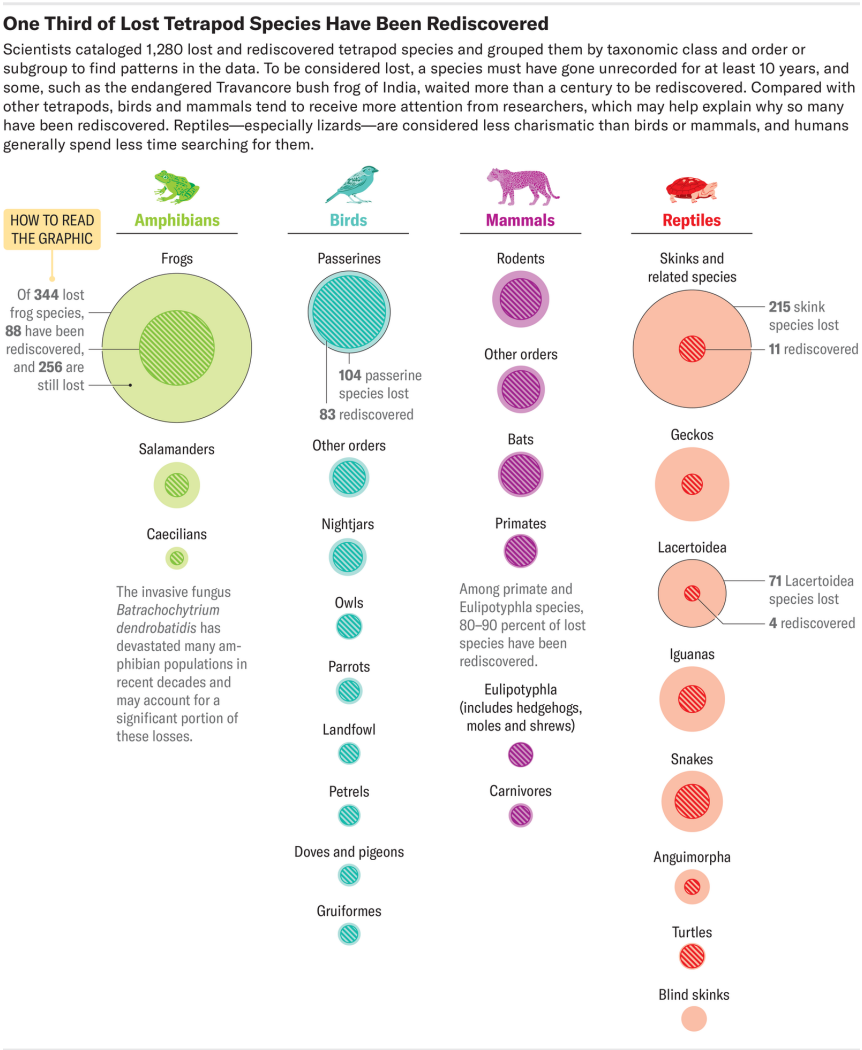
It can be painful for scientists to conclude that an entire species is gone forever. So after at least a decade without recorded sightings, local researchers sometimes declare a species temporarily "lost," hoping it may eventually be found again. In 2023 that hope led to rediscoveries of animals that included Attenborough's echidna, De Winton's golden mole in South Africa and the Victorian grassland earless dragon, a type of Australian lizard that went unseen for half a century. Such hope also fuels ongoing, decades-long searches for species such as the American Ivory-billed Woodpecker, which was last seen in 1944.

Now an international study published in *Global Change Biology* aims to "bring a bit of science to the search" for the mammals, amphibians, reptiles and birds playing hide-and-seek, according to senior study author Thomas Evans, a conservation scientist at the Free University of Berlin. Evans and researchers around the globe —in the U.S., China, Ecuador, South Africa, and more—spent two years compiling what they call the most exhaustive catalog ever of four-limbed creatures considered lost to science, as well as those that have been rediscovered.

The project started when Evans read "a huge, great, really depressing book" called Extinct Birds by paleontologist Julian P.

Hume. Along with the grim detail, the book came with a sliver of hope: an appendix listing lost species that were eventually found. Although there has been plenty of research into lost species, the study authors say that rediscoveries haven’t been thoroughly assessed since 2011. Analysis tallying losses and rediscoveries across animal groups is even rarer, Evans says.

The catalog Evans and his colleagues created indicates that 856 species are currently missing. And this number is growing faster than expedition parties can keep up with, despite increasingly sophisticated technology for identifying evidence of unseen creatures—including systems that detect environmental DNA traces of burrowing birds near the South Pole, software that disentangles the noises of different nocturnal species, and even techniques used to spot microscopic remnants of rare frogs in ship rats’ stomachs.



Credit: Amanda Montañez (*circles*), Brown Bird Design (*animals*); Source: "What Factors Influence the Rediscovery of Lost Tetrapod Species?" by Tim Lindken et al., in *Global Change Biology*. Published online January 17, 2024

Adding up losses and rediscoveries also suggests that roughly a quarter of lost species are likely already extinct. "It's kind of sad to think," Evans says, "but as far as we're concerned, people aren't going to find them." Analysis shows that many rediscovered species fit a certain profile: they are big, charismatic mammals or birds that tend to live across a range of habitats, often near humans and in more-developed countries. So, Evans says, if an animal fits this bill but continues to evade researchers after long searches, it is probably gone forever. The thylacine, or Tasmanian tiger, is a good example: since the last captive thylacine died in a zoo in 1936, the wolflike marsupial has inspired decades of fruitless searching. That fact strongly suggests that the thylacine is actually extinct, Evans

says, along with more than 200 other lost species that have also been thoroughly searched for.

On the other hand, creatures that don’t fit the profile for easy rediscovery, especially reptiles, could still be out there. Because they’re often hard to find and inspire less search effort, small, uncharismatic species are more likely to genuinely be lost but still alive, Evans says. His optimism is backed up by the numbers: new species of small reptiles continue to be discovered at a steady rate, and rediscoveries have boomed, with more than twice as many lost reptiles found between 2011 and 2020 as in the decade before.

The thylacine has acquired a Bigfoot-like status, complete with amateur hunters and highly questionable sightings. Meanwhile reptiles such as the Fito leaf chameleon of Madagascar are probably sitting pretty and waiting to be found. (Scientists haven’t yet reobserved this chameleon, partly because the French explorers who first described it in the 1970s named it “Fito”—a locally common place name that covers vast areas. No one knows where its exact range is, and few have looked.)

A probability analysis of some factors also rang “alarm bells” in different ways for different classifications of lost species, Evans says. Mammals classified as lost on islands, such as the Bramble Cay melomys, a rat lost in 2009 and declared extinct in 2016, are disproportionately likely to be gone for good, compared with mammals in other environments. There’s also a sweet spot for finding birds after they’ve been lost: 66 years, on average. This time span is long enough to raise interest in search expeditions but not so long that the animals would be presumed extinct. So the odds are not good for the more than a dozen bird species that were lost more than a century ago.

Evans hopes such details will help conservationists such as Christina Biggs, who has been curating a list of 25 “most wanted” species for Texas-based charity Re:wild since 2017. “We have

limited resources, and we have to make hard decisions on where to put that money," says Biggs, who is also one of the new study's 27 co-authors. "We want to prevent the most extinction we possibly can. [Evans's] research helps to direct us." Re:wild is currently using the study's findings to update its 2024 search lists.

But is being found always in a lost species' best interest? After a rediscovery, it can take months to secure an area from poachers or tourists. The researchers who spotted Attenborough's long-beaked echidna still have not revealed exactly where they saw it. "In publicizing something you've rediscovered, you're publicizing a food source for hunters," says biologist James Kempton, who led the echidna-finding expedition and wasn't involved in the cataloging study. Morib notes that in a dialect of the local Papuan language Tabla, the name for the echidna—amokalo—contains a word for "fat" because of the animal's desirable taste.

Camera trap photo of Attenborough's long-beaked echidna. Credit: Expedition Cyclops 2023

Biggs notes, however, that rediscoveries often galvanize protection efforts. "As soon as they're rediscovered, they go into a pipeline to have [protected area] designations made possible," she says. "Everything that we do could potentially save an entire other body of species in that same habitat. To me, that's a very hopeful thing." For instance, when the call of the Blue-eyed Ground Dove was

heard in 2015 in the Brazilian state of Minas Gerais, north of Rio de Janeiro, for the first time in 75 years, it sparked the creation of an 89,000-acre state park. Evans adds that for some of the most elusive species, researchers could use the study to decide if a creature is likely still alive—and then draw broad protected areas around its general region rather than send possibly fruitless expeditions to the area to prove the animal's existence.

Each extinct species comes with both an ecological and a cultural loss. Near the Cyclops Mountains, the Yongsu Sapari community once used echidnas as a "peace tool" to arbitrate disputes. "If brothers or friends fought, they had to find an echidna," Morib says—a solution that would be increasingly difficult.

The Hawaiian Crow, extinct in the wild, was thought to carry lost souls to their resting place. Now, outside of captivity, its call is only heard when Indigenous priests repeat a crow-like chant during traditional prayers. "Everything is connected," Biggs says. "Every single species does matter. It behaves in an ecosystem and fulfills a purpose within it that then underpins all of the life that we have on Earth."

A version of this article entitled "Lost and Found" was adapted for inclusion in the April 2024 issue of Scientific American. *This text reflects that version, with the addition of some material that was abridged for print.*

Daniel Shailer is a climate reporter based in Pittsburgh.

Pollinators Flock to Flower-Filled Solar Panel Fields

Solar farms seeded with wildflowers can boost pollinator populations

By Syris Valentine

Frederick Bass/Getty Images

Sprawling plains of solar panels can help nature more than just by providing clean energy: As populations of crucial pollinators decline, developers have been seeding the grounds of their solar arrays with native wildflowers. Now a five-year study published in *Environmental Research Letters* confirms that this approach boosts the pollinators' abundance and diversity—with spillover benefits for surrounding farms.

From 2018 through 2022, Argonne National Laboratory landscape ecologist Leroy J. Walston and his colleagues regularly visited two such arrays covering a dozen hectares each in southern Minnesota. The scientists recorded the number and kinds of pollinators the wildflowers attracted and found populations of bees, beetles,

butterflies, moths, and more had surged on-site—even as they continued declining elsewhere in the U.S.

Humans' pesticide use, greenhouse gas emissions and habitat destruction have sparked mass pollinator die-offs. Monarch butterfly numbers, for example, have plummeted by 80 percent nationwide in the past two decades, and according to the Center for Biological Diversity's 2017 report, nearly one in four native bee species is imperiled and at increasing risk of extinction. Further big losses would be disastrous for ecosystems and agriculture: 75 percent of North American plant species rely on pollinators. The federal government's energy goals require several million hectares for solar energy, with more than 80 percent of the projects planned for former agricultural land; seeding it this way could help save vanishing pollinators.

During their study, Walston and his team watched goldenrod soldier beetles flourish as their namesake flower, goldenrod, bloomed around the arrays. As other flowers unfurled, a symphony of insects appeared. Native bees saw the most staggering growth, with their population increasing 20-fold by the study's end. Monarch butterflies also increased in number and fluttered their dappled wings across the sites. Twice as many bees visited soybean fields adjacent to the solar sites as fields farther away, making the nearby plots' gains comparable to those of locations abutting land enrolled in conservation programs.

Developers have so far been slow to adopt wildflower planting, says Zara Dowling, an ecologist who oversees a pollinator-friendly certification program for solar facilities in Massachusetts. Owners of solar fields are often concerned about the risks of planting and uncertain about the true costs. But Dowling thinks that as incentives emerge and research is refined, it won't take much of a nudge to make the practice common. "From what I've heard," she says, "a lot of them are willing to do it if they can break even."

The idea's efficacy in other parts of the country—such as the desert Southwest—remains to be seen. Nevertheless, as Walston says, at least in the Midwest, "if you plant it, yeah, they'll come."

Syris Valentine is a freelance science journalist with a bachelor's degree in earth and space sciences from the University of Washington. You can follow them on most social media @ShaperSyris

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Culture

- **Readers Respond to the December 2023 Issue**
  Letters to the editors for the December 2023 issue of Scientific American

Readers Respond to the December 2023 Issue

Letters to the editors for the December 2023 issue of Scientific American

By Aaron Shattuck

Scientific American, December 2023

PITS OF DECAY

"Inside the Pit Factory," by Sarah Scoles, reports on how the U.S. is ramping up construction of new "plutonium pits" for nuclear weapons. Given that plutonium 239, one of the main ingredients in nuclear bombs, has a half-life of more than 24,000 years, why do the nuclear weapons from the late 20th century need to be "fixed"?

GLENN ANDERSEN *BUENA PARK, CALIF.*

SCOLES REPLIES: *It's true that the isotope of plutonium used in weapons has a significant half-life. But it is also decaying throughout that time, and as it does, it leaves behind other elements that contaminate the pit. This gives the pit a different composition than when it was made. The uranium atoms that are produced by the decay process also knock plutonium atoms out of their place in the structure, similarly changing the pit's properties. And all of this occurs while the plutonium is subject to more mundane chemical processes such as oxidation. So the gist is that with such changes, over time, a pit may not function as well or as safely as when it was new.*

LOGARITHMIC RULES

"This Unexpected Pattern of Numbers Is Everywhere," by Jack Murtagh [Math], discusses how nature seems to favor numbers beginning with a 1 or a 2, a phenomenon known as Benford's law. How could that possibly be? The puzzle even invaded my dreams, and in the morning the answer was clear: it means that randomness in nature is often distributed not linearly but rather logarithmically.

The reason this tendency makes a leading digit of 1 or 2 much more common than larger digits is related to the hybrid nature of our numbering system. Individual digits progress linearly: 1, 2, 3, 4. But the number places progress logarithmically: 1s, 10s, 100s, 1,000s. When we express logarithmically spaced items, the lower digits of 1 and 2 become much more common in the leading place than the other digits, just as on a logarithmic scale the length between 1 and 2 is greater than the length between 3 and 4.

Multiplying whatever quantity you are looking at or changing the units does not alter how the scale works.

CHRIS CHESNAKAS *STERLING, VA.*

Murtagh's article reminded me of using slide rules before we had digital calculators. I found one in a desk drawer and measured the spacing between the digits, and it correlated very closely to the number distribution in the article. Logarithms must lie at the bottom of the pattern.

GEORGE LANNERT *EVANSTON, ILL.*

Murtagh appears to be closer to answering the question of why Benford's law exists when he notes that it "is more likely to apply to data sets spanning several orders of magnitude." I suspect that the phenomenon is not a law of nature but an artifact of our choice of a notational system. If we instead chose to express the measurements of river lengths in base 16 or base 8, the distribution of digit occurrence would look very different.

GRANT RUTILA *BEVERLY HILLS, MICH.*

MURTAGH REPLIES: *Chesnakas and Lannert are absolutely correct. The probabilities we see in Benford's law are proportional to the distances between notches on a logarithmic scale (which is how numbers are laid out on a slide rule). Benford's law often arises in situations where the logarithm of the data is a uniform distribution. In fact, the mathematical definition of Benford's distribution makes this perspective clear: a leading digit n occurs with probability log(n + 1) – log(n) where the logarithms are base 10. For example, the probability of a leading 6 is log(7) – log(6).*

Rutila and other readers have wondered whether Benford's law is merely a quirk of the base 10 system. The phenomenon actually persists regardless of what base we use for our number system. To

calculate the probability distribution for other bases, we just have to change the base of the logarithms in the formula above.

ATOMIC LEGACIES

"Boom Times," Abe Streep's article about the communities shouldering the U.S.'s nuclear missile revival, resonates with my own family's atomic legacy. My mother grew up on the other side of the Iron Curtain during the height of the cold war. She was moved from town to town every year or two while her father, an army missile specialist, oversaw what she later surmised to be the construction of silos and installation of intercontinental ballistic missiles.

The immense psychological and physical harm from these projects continues to seep and reverberate through the land, affecting both the environment and the people decades later. The perpetrators (willing or unwilling, knowing or unknowing) are also victims. An individual can feel overwhelmed when contemplating the scale of these atomic legacies. But music and other arts can bring awareness to concepts that are too damaging to silently hold inside and too painful and complex to put into words. I do this in my own abstract musical compositions.

XENIA PESTOVA BENNETT *COUNTY DOWN, NORTHERN IRELAND*

DYSLEXIA AND LEARNING

"Misdiagnosing Dyslexia," Sarah Carr's article on how a flawed formula deprives children of help with reading, hit a nerve. I began teaching students with learning challenges in the 1970s, about when the term "learning disability" (LD) was introduced in my school. It was conceptualized as "unexplained underachievement." With respect to reading, the logic went like this: If you were smart

enough, you should be able to read. If you couldn’t, you must have a reading disability (dyslexia). Conversely, if you were not smart and couldn’t read well enough, this was likely because of a lower intelligence quotient (IQ) rather than an LD. Hence, the discrepancy model and the need to compare IQ with reading scores. The simplicity was compelling. School psychologists had well-developed tools for assessing intelligence and reading. It was a classic case of the tail wagging the dog.

Intelligence is devilishly complex to quantify meaningfully. It is also unstable and can change depending on a lot of things (culture, nutrition, experiences, and so on). Reading, in the broadest sense, is equally complex. Carr mentions phonological awareness (PA) as a valid approach to ameliorating dyslexia. I believe this to be accurate, but success with true meaning making (that is, comprehension) requires more. PA is like using training wheels while you are learning to ride a bike. Eventually the wheels need to come off.

JOE MORIN *CALGARY, ALBERTA*

I am a certified, experienced school psychologist who has worked in Arizona, Nebraska and Illinois. I am very concerned about the portrayal of school psychologists in Carr’s article about diagnosing dyslexia. School psychologists are on the front line of advocating for more valid and useful processes for identifying students with dyslexia and other learning disabilities but are often limited in practice by outdated special education laws that do not reflect up-to-date scientific practice standards. We are more than capable of looking beyond IQ tests and using less biased and more useful assessment procedures that are based on current dyslexia research.

REGINA BOLAND *VIA E-MAIL*

Aaron Shattuck is a senior copy editor at *Scientific American*.

Engineering

- **Collaborating in Person May Spark More Innovative Research**
  Bringing people together virtually doesn’t seem to boost disruptive research

Collaborating in Person May Spark More Innovative Research

Bringing people together virtually doesn't seem to boost disruptive research

By Simon Makin

skynesher/Getty Images

Many people assume today's easy long-distance collaboration should release an unprecedented flood of innovative scientific research—but, oddly, a new study suggests the opposite may be true.

Several reasons have been suggested for an apparent slowdown in bold new research ideas, but it now seems remote collaboration itself may be a limiting factor. For a recent study in *Nature*, University of Pittsburgh social scientist Lingfei Wu and his colleagues found that teams collaborating remotely produce fewer breakthroughs.

The researchers analyzed 20 million research papers published between 1960 and 2020 and four million patents filed between

1976 and 2020. They assessed how “disruptive” these were by analyzing citations and scoring each from –1 to 1, where 1 means highly disruptive. Highly disruptive studies were defined as those that eclipse earlier work and open new avenues of research; articles that cite them usually don’t also cite earlier studies they build on. Less disruptive studies incrementally build on previous work, and articles citing them typically also cite preceding studies.

The researchers found that as the distance between authors’ workplaces increases from zero to at least 600 kilometers, their papers’ probability of being disruptive (having a score above 0) falls by roughly a quarter. This relation holds across varying team sizes, time periods and fields.

To investigate why, Wu and his team analyzed researchers’ self-reported roles. They found that those working together in person were more likely to focus on conceptual tasks—the kind of work apt to produce disruptive new ideas. Researchers collaborating remotely were more likely to do technical work such as data analysis.

The team also found that when researchers were convening in person, even big differences between individuals’ citation numbers had little effect on the likelihood of their collaborating on conceptual work. But in remote teams, the chances of researchers jointly conceiving ideas declined drastically when one had

significantly more citations than the other. “The finding that on-site teams better integrate junior scholars into conceptual tasks and serve as an escalator for new talent is powerful and timely,” says University of Arizona sociologist Erin Leahey, who studies specialization, disruption and collaboration. “In this era of proliferating remote collaboration, it’s important for us to know the critical contributions that in-person collaborations make.”

The findings challenge the assumption that merely connecting people online leads to the growth of new ideas. “There’s something missing in this formula,” Wu says. In theory, remote collaboration enables more new combinations of knowledge—but Wu believes it also makes it harder to put the pieces together. “If you want to encourage radical innovation, you’ve got to bring people together,” he says. “You cannot just rely on digital infrastructure.”

Simon Makin is a freelance science journalist based in the U.K. His work has appeared in *New Scientist*, the *Economist*, *Scientific American* and *Nature*, among others. He covers the life sciences and specializes in neuroscience, psychology and mental health. Follow Makin on X (formerly Twitter) @SimonMakin

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Ethics

- **Evidence Does Not Support the Use of the Death Penalty**
  Capital punishment must come to an end. It does not deter crime, is not humane and has no moral or medical basis
- **The Dangers of Fast Science**
  Scientific research needs to slow down, not speed up, to produce trustworthy results

Evidence Does Not Support the Use of the Death Penalty

Capital punishment must come to an end. It does not deter crime, is not humane and has no moral or medical basis

By The Editors

A death penalty vigil, held in 2021 outside an Indiana penitentiary.
Bryan Woolston/Reuters/Redux

It is long past time to abolish the death penalty in the U.S.

Capital punishment was halted in the U.S. in 1972 but reinstated in 1976, and since then, nearly 1,600 people have been executed. To whose gain? Study after study shows that the death penalty does not deter crime, puts innocent people to death, is racially biased, and is cruel and inhumane. It is state-sanctioned homicide, wholly ineffective, often botched, and a much more expensive punishment than life imprisonment. There is no ethical, scientifically supported, medically acceptable or morally justifiable way to carry it out.

The recent execution of Kenneth Eugene Smith demonstrates this barbarity. After a failed attempt at lethal injection by prison

officials seemingly inexperienced in the placement of an IV, the state of Alabama killed Smith in January using nitrogen gas. The Alabama attorney general claimed that this method of execution was fast and humane, despite no supporting evidence. Eyewitnesses recounted that Smith thrashed during the nitrogen administration and took more than 20 minutes to die.

Opposition to the death penalty is growing among the American public, and the Biden administration must follow through on its promise to end this horror. The Department of Justice must heed its own admission that the death penalty doesn’t stop crime, and our legislators must continue to take up the issue on the congressional floor. The few states that still condemn people to death must follow the lead of states that have considered the evidence and rejected capital punishment.

Programs such as the Innocence Project have shown, over and over, that innocent people have been sentenced to death. Since 1973 nearly 200 people on death row have been exonerated, based on appeals, the reopening of cases, and the entrance of new and sometimes previously suppressed evidence. People have recanted testimony, and supposedly airtight cases have been poked full of evidentiary holes.

Through the death penalty, the criminal justice system has killed at least 20 people now believed to have been innocent and uncounted

others whose cases have not been reexamined. Too many of these victims have been Black or Hispanic. This is not justice. These are state-sanctioned hate crimes.

Using rigorous statistical and experimental control methods, both economics and criminal justice studies have consistently found that there is no evidence for deterrence of violent crimes in states that allow capital punishment. One such study, a 2009 paper by criminology researchers at the University of Dallas, outlines experimental and statistical flaws in econometrics-based death penalty studies that claim to find a correlated reduction in violent crime. The death penalty does not stop people from killing. Executions don't make us safer.

The methods used to kill prisoners are inhumane. Electrocution fails, causing significant pain and suffering. Joel Zivot, an anesthesiologist who criticizes the use of medicines in carrying out the death penalty, has found (at the request of lawyers of death row inmates) that the lungs of prisoners who were killed by lethal injection were often heavy with fluid and froth that suggested they were struggling to breathe and felt like they were drowning. Nitrogen gas is used in some veterinary euthanasia, but based in part on the behavior of rats in its presence, it is "unacceptable" for mammals, according to the American Veterinary Medical Association. This means that Smith, as his lawyers claimed in efforts to stop his execution, became a human subject in an immoral experiment.

Courts have often decided, against the abundant evidence, that these killings are constitutional and do not fall under the "cruel and unusual punishment" clause of the 8th Amendment or, in Smith's appeal, both the 8th Amendment and the due process protection clause of the 14th amendment.

A small number of prosecutors and judges in a few states, mostly in the South, are responsible for most of the death sentences being

handed down in the U.S. today. It’s a power they should not be able to wield. Smith was sentenced to life in prison by a jury before the judge in his case overruled the jury and gave him the death sentence.

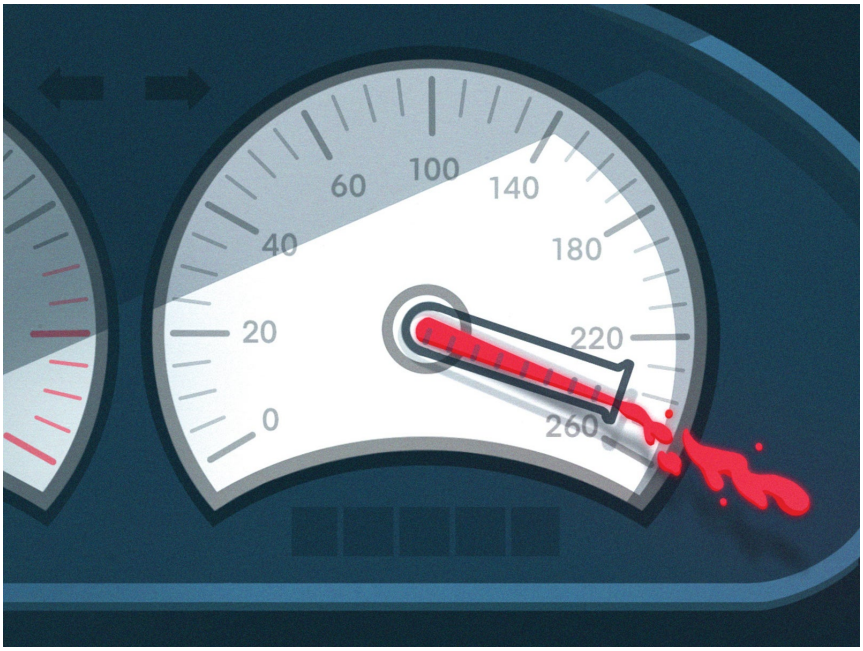
A furious urge for vengeance against those who have done wrong—or those we think have done wrong—is the biggest motivation for the death penalty. But this desire for violent retribution is the very impulse that our criminal justice system is made to check, not abet. Elected officials need to reform this aspect of our justice system at both the state and federal levels. Capital punishment does not stop crime and mocks both justice and humanity. The death penalty in the U.S. must come to an end.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

The Dangers of Fast Science

Scientific research needs to slow down, not speed up, to produce trustworthy results

By Naomi Oreskes



Jarred Briggs

A theme at this year's World Economic Forum (WEF) meeting in Davos, Switzerland, was the perceived need to "accelerate breakthroughs in research and technology." Some of this framing was motivated by the climate emergency, some by the opportunities and challenges presented by generative artificial intelligence. Yet in various conversations, it seemed to be taken for granted that to address the world's problems, scientific research needs to move faster.

The WEF mindset resonates with the Silicon Valley dictate—usually credited to Mark Zuckerberg—to move fast and break things. But what if the thing being broken is science? Or public trust?

The WEF meeting took place just a fortnight after Harvard University President Claudine Gay stepped down after complaints were made about her political science scholarship. Gay's troubles came on the heels of the resignation of Stanford University President Marc Tessier-Lavigne, after an internal investigation concluded that his neuroscience research had "multiple problems" and "fell below customary standards of scientific rigor." In response, Gay requested corrections to several of her papers; Tessier-Lavigne requested retraction of three of his. Although it may be impossible to determine just how widespread such problems really are, it's hard to imagine that the spectacle of high-profile scholars correcting and retracting papers has not had a negative impact on public trust in science and perhaps in experts broadly.

In recent years we've seen important papers, written by prominent scientists and published in prestigious journals, retracted because of questionable data or methods. In one interesting case, Frances H. Arnold of the California Institute of Technology, who shared the 2018 Nobel Prize in Chemistry, voluntarily retracted a paper when her lab was unable to replicate her results—but after the paper had been published. In an open apology, she stated that she was "a bit busy" when the paper was submitted and "did not do my job well." Arnold's honesty is admirable, but it raises a question: Are scholars at übercompetitive places such as Harvard, Stanford and Caltech

rushing to publish rather than taking the time to do their work right?

It's impossible to answer this question scientifically because there's no scientific definition of what constitutes "rushing." But there's little doubt that we live in a culture where academics at leading universities are under tremendous pressure to produce results—and a lot of them—quickly.

The problem is not unique to the U.S. In Europe, formal research assessments—which are used to allocate future funding—have for years judged academic departments largely on the quantity of their output. A recent reform urging an emphasis on quality over quantity allowed that the existing system had created "counterincentives."

Good science takes time. More than 50 years elapsed between the 1543 publication of Copernicus's magnum opus, *De Revolutionibus Orbium Coelestium (On the Revolutions of the Heavenly Spheres),* and the broad scientific acceptance of the heliocentric model of the universe. Nearly a century passed between biochemist Friedrich Miescher's identification of the DNA molecule and suggestion that it might be involved in inheritance and the elucidation of its double-helix structure in the 1950s. And it took just about half a century for geologists and geophysicists to accept geophysicist Alfred Wegener's idea of continental drift.

There's plenty of circumstantial evidence that scientists and other scholars are pushing results out far faster than they used to. Consider the sheer volume of academic papers being published these days. One recent study put the number at more than seven million a year, compared with fewer than a million as recently as 1980. Another study found 265 academic authors—two thirds of whom were in the medical and life sciences—who published a paper *every five days* on average.

Some of this growth is driven by more scientists and more co-authorship of papers, but the numbers also suggest that the research world has prioritized quantity over quality. Researchers may need to slow down—not speed up—if we are to produce knowledge worthy of trust.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

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 *The Big Myth* (Bloomsbury, 2023).

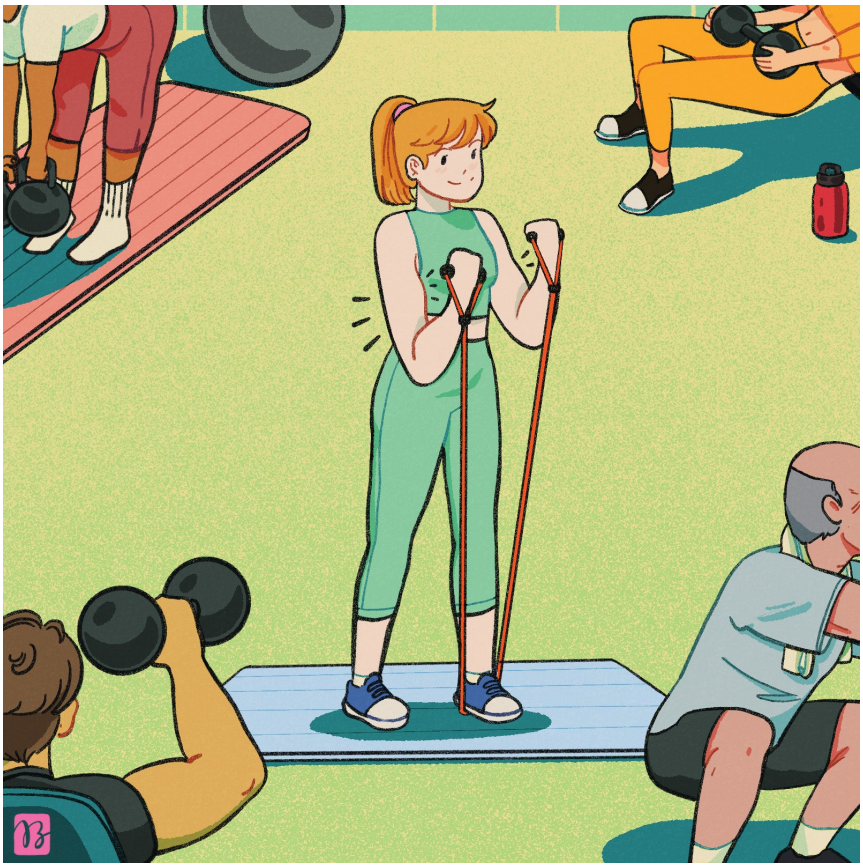
Exercise

- **Simple Resistance Exercises Improve Overall Health and Reduce Death Risks**
  Weight training turns out to be as important as aerobic activity for warding off disease

Simple Resistance Exercises Improve Overall Health and Reduce Death Risks

Weight training turns out to be as important as aerobic activity for warding off disease

By Lydia Denworth



Jay Bendt

I've always been unwilling to be pressed into bench-pressing. Lifting weights seemed the province of serious athletes looking to improve performance or men looking to bulk up. Instead I walk several miles every day and do yoga regularly. But although research into resistance and strength training is still catching up to that on aerobic exercise, there's growing evidence that muscle-strengthening routines confer a host of physical and cognitive

advantages, some of which can’t be achieved through aerobic workouts alone.

We do not just need to get our steps in; we need to get in reps—as in curls, push-ups and squats. That’s why the federal Physical Activity Guidelines for Americans, the World Health Organization, and others specify two or more sessions a week of muscle-strengthening activities. They mean weight-bearing exercises of moderate or greater intensity involving all major muscle groups. That’s in addition to 150 to 300 minutes of moderate to vigorous aerobic activity. Yet at least three quarters of Americans fail to hit both the aerobic and the strength targets, and the latter is especially rarely met.

All exercise is a form of physical stress. Done correctly, it creates better fitness by making the body adapt to that stress and become stronger. Like aerobic exercise, resistance training increases heart rate and makes the lungs work more to keep the additional blood flow filled with oxygen. But the primary benefit of muscle-strengthening activity comes from the way it taxes the muscles. Pushing or pulling against resistance generates microscopic tears in muscle tissue. These tiny tears are not really damaging: they prompt the muscle to repair itself and build more fibers to become stronger. “You’re trying to hurt yourself for an adaptive benefit,” says epidemiologist and exercise scientist Jessica Gorzelitz of the University of Iowa.

In 2022 an analysis of several studies found that muscle-strengthening exercises were associated with a 10 to 17 percent lower risk of all-cause mortality than in people who didn’t do such exercises. And the same year, Gorzelitz and her colleagues used data on nearly 100,000 older Americans to show that those who did both aerobic and resistance training had the lowest mortality risk in the entire group. Weightlifting, by itself, also reduced the risk of death from all causes as well as from cardiovascular disease specifically.

These activities don’t just keep us alive—they keep us healthier while we are living. We lose 3 to 8 percent of our muscle mass every decade after the age of 30 and more after age 60. But muscle strengthening allows us to push back against the aging process and build lean body mass. This fosters metabolic health and keeps us lifting our own suitcases and carrying our own groceries. Resistance training also builds better bones—muscles pull on bones, and in response, bones add new cells and get stronger, increasing bone mineral density, which is especially important for women as they age.

In cancer survivors, studies show that muscle-strengthening exercises improved cancer-related fatigue and health-related quality of life. Resistance training also helps to prevent and control diabetes, in part by improving blood glucose storage and circulation. And studies have found that strength training is associated with reductions in anxiety and depression.

Some of the resistance to resistance training is because, compared with aerobic exercise, it’s more complex. With aerobic activities, a step is a step, whether you walk, jog, run or hike, and those steps are easily tracked. But muscle-strengthening exercises include far more variables, says physiologist William Kraemer of the Ohio State University. People need to choose which parts of the body to work and in what order, which equipment to use, what intensity to work at, and how often to rest. For instance, it’s often wise to work

large muscle groups before smaller ones, and it's critical to allow sufficient rest between workouts. Kraemer says those rest periods allow the all-important repair process to begin.

Any form of resistance training will do—pulling on strong elastic bands, push-ups, free weights or weight machines—so long as it puts strain on your muscles. Experts advise that people start small so as not to get hurt. With weights, "you don't have to immediately jump to hang cleans and deadlifts," Gorzelitz says.

And aim for the recommended minimum of two sessions per week, although for some people more frequent, shorter sessions might be more sustainable. "You want it to become a habit," points out Anne Brady, who is a clinical exercise physiologist at the University of North Carolina Greensboro and who coaches private clients online.

Brady advises people who find the gym intimidating or too expensive to get a set of weights or elastic resistance bands for use at home. Professional advice from a trainer is useful, especially at the beginning, she says, but free online videos are "a great starting point." If you go online, look for presenters with certifications from the American College of Sports Medicine or who are recommended by reputable organizations such as AARP.

It's important to increase weight and intensity over time, a concept known as progressive resistance. Completing three sets with a five-pound dumbbell is challenging for a beginner but provides little benefit to a gym regular. "If you keep doing the same thing over and over again, no adaptations occur," Kraemer says.

That's a message to take to heart—and to the rest of our bodies. Most of us could strengthen our health by adding strength training to our routines.

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American.

Lydia Denworth is an award-winning science journalist and contributing editor for *Scientific American*. She is author of *Friendship* (W. W. Norton, 2020).

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Extraterrestrial Life

- **Here's What I Learned as the U.S. Government's UFO Hunter**
  A forthcoming investigational report from an office of the Pentagon has found no evidence of aliens, only allegations circulated repeatedly by UFO claim advocates

Here’s What I Learned as the U.S. Government’s UFO Hunter

A forthcoming investigational report from an office of the Pentagon has found no evidence of aliens, only allegations circulated repeatedly by UFO claim advocates

By Sean Kirkpatrick

Scott Brundage

Carl Sagan popularized the maxim that “extraordinary claims require extraordinary evidence.” This advice should not be optional for policy makers. In today’s world of misinformation, conspiracy driven decision-making and sensationalist-dominated governance, our capacity for rational, evidence-based critical thinking is eroding, with deleterious consequences for our ability to effectively deal with multiplying challenges of ever increasing complexity.

As director of the Department of Defense’s All-Domain Anomaly Resolution Office (AARO), charged by Congress in 2022 to help bring science-based clarity and resolution to the long-standing mystery surrounding credible observations of unidentified

anomalous phenomena (UAP), also known as UFOs, I experienced this erosion up close and personal. And it was one factor in my decision to step down from my position last December. After painstakingly assembling a team of highly talented and motivated personnel and working with them to develop a rational, systematic and science-based strategy to investigate these phenomena, our efforts were ultimately overwhelmed by sensational but unsupported claims that ignored contradictory evidence yet captured the attention of policy makers and the public, driving legislative battles and dominating the public narrative.

The result of this whirlwind of tall tales, fabrication and secondhand or thirdhand retellings of the same, was a social media frenzy and a significant amount of congressional and executive time and energy spent on investigating these so-called claims—as if we didn't have anything better to do.

The conspiracists' story goes something like this: The U.S. has been hiding and attempting to reverse engineer as many as 12 UAP/UFOs from as early as the 1960s and perhaps earlier. This great cover-up and conspiracy failed to produce any salient results, and consequently the effort was abandoned to some private sector defense contractors to continue the work. Sometime later, the story continues, those private sector contractors wanted to bring the whole program back under U.S. government (USG) auspices. Apparently, the CIA stopped this supposed transfer back to the

USG. All of this is without substantiating evidence, but, alas, belief in a statement is directly proportional to the volume in which it is transmitted and the number of times it is repeated, not the actual facts.

During a full-scale, year-long investigation of this story (which has been told and retold by a small group of interconnected believers and others with possibly less than honest intentions—none of whom have firsthand accounts of any of this), AARO discovered a few things, and none were about aliens.

First, no record exists of any president or living DOD or intelligence community leader knowing about this alleged program, nor any congressional committee having such knowledge. This should speak volumes if this case were following typical procedure because it is inconceivable that a program of such import would not ever have been briefed to the 50 to 100 people at the top of the USG over the decades of its existence.

Second, this narrative has been simmering for years and is largely an outgrowth of a former program at the DOD's Defense Intelligence Agency (DIA) called the Advanced Aerospace Threat Identification Program (AATIP), which was heavily influenced by a group of individuals associated with businessman and longtime ufologist Robert Bigelow, founder of Bigelow Aerospace. In 2009 then senator Harry Reid asked the secretary of defense (SECDEF) to set up a SAP (special access program) to protect the alleged UAP/UFO material that AATIP proponents believed the USG was hiding. The SECDEF declined to do so after a review by the Office of the Undersecretary of Defense for Intelligence (OUSDI), and DIA concluded that not only did no such material exist, but taxpayer money was being inappropriately spent on paranormal research at Skinwalker Ranch in Utah. This is well documented in open sources, particularly in records available on DIA's electronic FOIA Reading Room. After the negative response by SECDEF, Senator Reid then enlisted the help of then senator

Joseph Lieberman to request that the Department of Homeland Security (DHS) set up an SAP for the same purpose. The administrative SAP proposal package was informed by the same individuals who had been associated with AATIP. AARO's archival research has located the administrative proposal for the DHS SAP, complete with the participants, which has been declassified and is being reviewed for public release.

Finally, the key purveyors of this narrative have known one another for decades. In the early 2000s several members of this small group also participated in a study, erroneously characterized (by the same participants) as having been sponsored by the White House, on the possible societal impact of disclosing the existence of extraterrestrials to the public, with the authenticity of the abovementioned concealed government program taken as its baseline assumption. The think tank in question was a "futures" enterprise that often worked on fringe studies, and many of the individuals involved with the study also worked for Bigelow Aerospace in support of the AATIP program.

AARO thoroughly investigated these claims as part of its congressionally mandated mission to not only technically evaluate contemporary UAP observations but also review historical accounts going back to the 1940s. One of my last acts before retiring was to sign AARO's *Historical Record Report Volume 1,* which is currently being prepared for delivery to Congress and the public. The report demonstrates that many of the circulating allegations described above derive from inadvertent or unauthorized disclosures of legitimate U.S. programs or related R&D that have nothing to do with extraterrestrial issues or technology. Some are misrepresentations, and some derive from pure, unsupported beliefs. In many respects, the narrative is a textbook example of circular reporting, with each person relaying what they heard, but the information often ultimately being sourced to the same small group of individuals.

The operational mission Congress has assigned AARO is important. Accumulating observations by highly trained U.S. military and other credible personnel of unidentified anomalous phenomena at or near sensitive national security areas and activities calls for a serious effort to understand what's going on. Simply put, "unidentified" is unacceptable, particularly in these times of heightened geopolitical tension. Part of the problem we face today, however, is that the modern media cycle drives stories faster than sound research, science and peer review time lines can validate them. More worrisome is the willingness of some to make judgments and take actions on these stories without having seen or even requested supporting evidence, an omission that is all the more problematic when the claims are so extraordinary. Some members of Congress prefer to opine about aliens to the press rather than get an evidence-based briefing on the matter. Members have a responsibility to exhibit critical thinking skills instead of seeking the spotlight. As of the time of my departure, none, let me repeat, none of the conspiracy-minded "whistleblowers" in the public eye had elected to come to AARO to provide their "evidence" and statement for the record despite numerous invitations. Anyone that would rather be sensationalist in the public eye than bring their evidence to the one organization established in law with all of the legal process and security framework established to protect them, their privacy, and the information and to investigate and report out findings is suspect.

I can assure you as its former director that AARO is unwaveringly committed to harnessing science and technology to bring unprecedented clarity to these fascinating, important, and stubborn mysteries and to do so with maximum transparency. Its talented staff and team of supporting scientists are at this very moment striving in collaboration with the armed forces, intelligence community, government agencies, national laboratories, scientific community, academic community—and soon the general public—to collect and analyze hard, measurable data—i.e., extraordinary

evidence—in this heretofore eyewitness-rich but data-poor field. The AARO team will go wherever the data takes it, without fail, and will not be swayed by any attempts to influence its findings otherwise. Science cannot be left on the side of the road in the mad dash to uncover some great conspiracy. Carl Sagan would expect no less, and neither should the American people.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

A version of this article with the title "Observations from a Government UFO Hunter" was adapted for inclusion in the April 2024 issue of Scientific American.

Sean Kirkpatrick recently retired from federal service as the first director of the All-Domain Anomaly Resolution Office at the U.S. Department of Defense. He holds a Ph.D. in physics from the University of Georgia.

Health Care

- ## We Need to End Obstetric Fistula
  Obstetric fistula is almost entirely preventable yet flourishes in places where health care is inaccessible for too many women

We Need to End Obstetric Fistula

Obstetric fistula is almost entirely preventable yet flourishes in places where health care is inaccessible for too many women

By Ashley Judd

Ashley Judd, an actor and goodwill ambassador for the United Nations Population Fund (UNFPA), visits a gynecology clinic for Syrian refugee women funded by UNFPA in the Zaatari Refugee Camp in Jordan in 2016.
Jordan Pix/Getty Images

I chose not to have children, yet several communities where I have worked in the Democratic Republic of the Congo know me as Maman Ashley. This is how core to womanhood motherhood is. The way we revere motherhood is universal. Paradoxically, the way we normalize the suffering of mothers is also universal.

We see this in how women are denied pain management when in labor, regardless of income. We see this in the depleted budgets for maternal health services and in the unacceptable increase in the global rate of maternal mortality—women dying during pregnancy or childbirth, often from preventable causes. We see it, heartbreakingly, in the persistence of injuries such as obstetric fistula, an almost entirely preventable childbirth trauma.

Obstetric fistula happens when women go through prolonged labor without medical care, and a hole develops between the birth canal and either the bladder or the rectum. Without maternal health care and treatment, it is one of the most ghastly and debilitating injuries that childbirth can cause, affecting an estimated two million women and girls worldwide. It is also the most common obstetric concern in lower-income countries.

I have seen the toll these horrific injuries take on women during my travels as a goodwill ambassador for the United Nations Population Fund (UNFPA), the U.N.'s sexual and reproductive health agency. In the DRC, I witnessed a fistula repair surgery, the mother gripping my right hand, my left wiping her brow, as doctors sewed her perforated vagina. Some years later a woman named Marima invited me to attend her surgery in South Sudan. She had been living with a torn rectum and vagina for seven years, incontinent and covered with bedsores and ulcers. She had suffered through nine disastrous days of obstructed labor at home, with no midwife and the nearest health clinic out of both physical and financial reach.

Last year I asked in an op-ed in *USA Today* if we as a society truly value mothers. Having now spent both my first birthday and my first Mother's Day without my own mom, that question continues to haunt me. The numbers of pregnant women and girls dying every year—largely from preventable causes—are shattering:

Nearly 300,000 perished in 2020. That is one mother, some in their early teens, every two minutes. Some 6 percent of these deaths are from obstetric fistulas, and for each of those deaths, as many as four to five more women will live with an obstetric fistula injury. Why such grim numbers? Because the women afflicted by obstetric fistulas face systemic gender discrimination and social marginalization. They were born into impoverished communities depleted of resources, where sexual and reproductive health concerns are largely neglected, even though these concerns are essential for human life.

This suffering must stop. We must revere the mother as much as we revere motherhood, and we must invest in maternal health care. Women worldwide should have access to qualified midwives and other health workers while they are trying to give life to another human being. And we must fight for the right to contraception: Half of all pregnancies in the world are not intended. Too many women and girls cannot get the contraception they need or want, because they don't know where to go or can't afford it or their partners don't want them to use it.

UNFPA has worked relentlessly for two decades to end obstetric fistula, enabling more than 129,000 women, many living in places of extreme poverty, to have life-changing repair surgeries.

In the developed world, few of us have ever heard of obstetric fistula, perhaps because we do not talk openly about vaginas. We certainly don't want to talk about the ones that are damaged, violently torn in prolonged childbirth. It is especially galling that fistula happens to adolescent girls who are forced to marry men. Their young pelvises are not adequately developed for childbirth, and obstructions are more common. Women with fistulas are often ostracized by their own communities, abandoned even by their closest family. Adding tragedy to trauma, in nine out of 10 births that result in a fistula, the baby will die.

Repairing these women's bodies can be dangerous work in places where sexual violence is rampant. In addition to supporting women with obstetric fistula, we—the citizens of the world and members of the human family—must support the health-care workers who risk their lives to restore these women's bodily functions and help them reclaim their dignity. The surgery I witnessed in the eastern Congo was at Panzi Hospital, whose founder, gynecologist Denis Mukwege, has been awarded the Nobel Peace Prize for his work repairing fistula in spite of attempts on his life. He is now living with full-time security, locked inside his medical compound. He and other surgeons operate under dire circumstances. Prior to surgery, they have to scrub their hands with water from the river and a bar of soap. During the operation I watched, the electricity went down for hours before sparking back on.

Marima's surgery was in a public hospital in the war-ravaged town of Bentiu. UNFPA had flown in surgeons from Uganda and Nigeria to South Sudan to repair her fistula and several others'. I visited the mothers in that ward on their small cots. They were smiling and eagerly awaiting their turn in the operating room. They told me their upcoming surgeries revived their hopes that they could take better care of their children.

The women most likely to incur fistulas are also the women least likely to access a school, join the workforce, own property, or choose if, when and whom they will marry—and at what age. We must fund programs that help survivors reintegrate into the societies that shamed and rejected them. If they learn new skills, they can earn their own living and make choices about whether, when and how many children they will have.

Unforgivable inequalities result in health and social systems ignoring the most marginalized women and girls in their moment of greatest need—when trying to bring new life into the world. We must demand—with them—investments in reproductive health

care, accountability at all levels, and action to end gender discrimination.

In December 2022 U.N. Member States adopted a resolution committing to end fistula by 2030. If we don't support this resolution, we are morally contradicting ourselves. We cannot revere motherhood while allowing fistula to tear women to pieces. We must show up for mothers who experience such needless trauma.

While I will never understand what these women have gone through, I do understand the challenges of health care in such underdeveloped places. Two years ago, during my annual stay in a Congolese rainforest, I tripped over a tree root and broke my leg in four places. The only painkiller available was a stick to bite on. A man named Jean set my leg twice, and others improvised a stretcher. After 67 hours of being carried through the rainforest, riding on a motorbike while holding my loose bones together with my hands, and traveling by bush plane, I came to a Level 1 trauma unit in Johannesburg. After this experience, I often think of the mothers who go through childbirth without any of the help I received, and it stokes my fire to help them further.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

Ashley Judd is an actor, activist and public speaker. She is co-author of *All That Is Bitter and Sweet: A Memoir* (Ballantine Books, 2012) and serves as a goodwill ambassador for UNFPA, the United Nations agency for sexual and reproductive health.

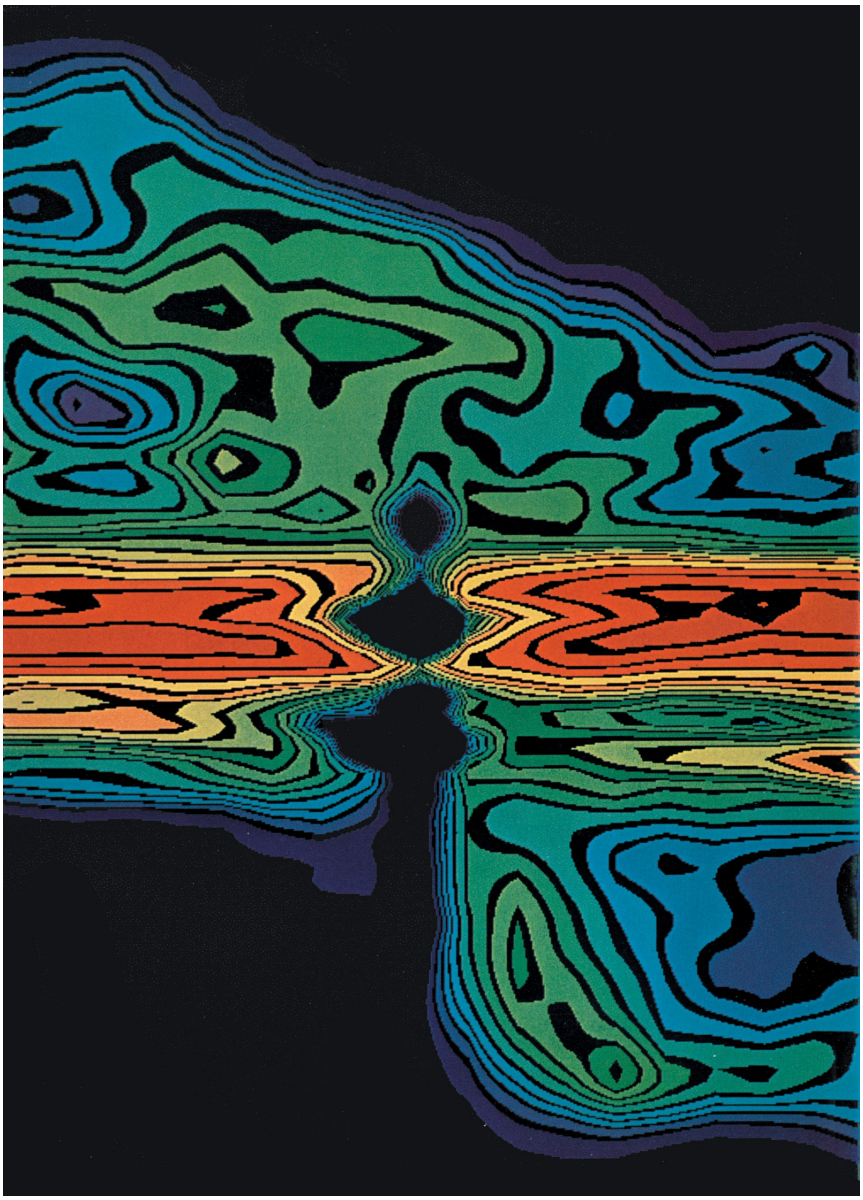
History

- **April 2024: Science History from 50, 100 and 150 Years Ago**
  Chromosome cats; Louis Pasteur, master brewer

April 2024: Science History from 50, 100 and 150 Years Ago

Chromosome cats; Louis Pasteur, master brewer

By Mark Fischetti



1974, Gassy Galaxy: "Gas motions at our galactic center are displayed. The map shows the distribution of emission from un-ionized hydrogen. The different colors indicate intensity, from violet (*lowest*) to red (*highest*). The vertical axis indicates the velocity of hydrogen lying in the galactic plane: velocities toward us are negative; velocities away from us are positive. The horizontal red ridge is centered at zero velocity."
Scientific American, Vol. 230, No. 4; April 1974

1974

Herbicidal Warfare in Vietnam

“Between 1962 and 1971 U.S. forces sprayed 20 million gallons of herbicidal chemicals on some four million acres of South Vietnam, or about a tenth of the country’s land surface. The objectives were primarily to defoliate trees and thus uncover enemy troop concentrations and to destroy crops destined for enemy stomachs. The environmental war has now been assessed by the national academy of sciences. Among the conclusions are that serious long-term damage was done to Vietnamese forests, that the fertility of cropland was probably not adversely affected and that it is too soon to be sure whether or not humans were made sick or genetically damaged, or will be in the future.”

Research since then, of course, determined that many people in Vietnam were harmed, short term and long term.

Chromosome Cats

“A ‘tortoiseshell’ cat is a mixture of orange and black, usually blended together rather than in patches; a ‘calico’ cat is tortoiseshell and white, usually in patches. Most tortoiseshell and calico cats are female. Males are rare and tend to be infertile. It appears that the existence of most, and perhaps all, tortoiseshell

and calico male cats can be explained by abnormalities in their sex-chromosome complement."

1924

Crude Oil: Vegetable or Mineral?

"No authority is prepared to state definitely whether oil should be spoken of as organic or mineral. It is possible that in remote geological times during some convulsion, animal life, whether of the land or sea, together with much vegetable growth, died and was submerged with the sandy formation in which the oil is now found, and that the heavy petroleum oil represents what is left of these organic materials. This, however, is no more than a surmise. But how is it that oil is classed by the geologists as among the minerals? It is found in mineral formation, and the process by which it is recovered is among the mining activities. Someday investigation may establish its true origin. Until that time, it will be correct to speak of it as a mineral."

1874

Sahara Lake, Not Desert

"French engineers have proved that the surface of the great Desert of Sahara is below the level of the ocean, in fact that it is the bottom of an ancient freshwater lake which has dried up. It has been therefore suggested to change this desert back into a lake. This would create a moist atmosphere in place of the burning hot, dusty whirlwinds which are the curse of that region. there are, however, no rivers to be turned into the basin. It has, therefore, been proposed to make a channel to the ocean, and lead the ocean water into the desert; but in consequence of vigorous evaporation in that latitude, the water, when spread out over any considerable

surface, would probably disappear as quickly as even the largest canal could pour it in."

Louis Pasteur, Master Brewer

"The liability of beer to turn sour is due to the presence of special ferments derived from the air, and from the materials used. By boiling the infusion of malt and hops, cooling out of contact with air and fermenting with a pure yeast in vessels to which only carbonic acid or pure air is admitted, a beer is produced of superior quality, which may be preserved without trouble for any time. The author makes use of the fact that oxygen favors the growth of true yeast but hinders the propagation of the other ferments. Pure yeast when kept in pure air undergoes no change, even at summer temperatures. The *mycoderma vini* does not, as the author once thought, become changed; it acts as an alcoholic ferment, but does not propagate itself." —Louis Pasteur

Microbiologist Louis Pasteur famously developed early vaccines in the 1800s. Perhaps today he would have become a craft brewer instead.

Swollen Retina Means Death

"At the moment of death, there become disengaged from venous blood certain gases which are normally confined therein, and which form a pneumatosis or swelling of the veins. This action in the veins of the retina, says M. Bonchut, is easily appreciable by the ophthalmoscope, and constitutes an immediate and certain sign of death."

Mark Fischetti has been a senior editor at *Scientific American* for 17 years and has covered sustainability issues, including climate, weather, environment, energy, food, water, biodiversity, population, and more. He assigns and edits feature articles, commentaries and news by journalists and scientists and also writes in those formats. He edits History, the magazine's department looking at science advances throughout time. He was founding managing editor of two spinoff magazines: *Scientific American Mind* and *Scientific American Earth 3.0*. His 2001 freelance article for the magazine, "Drowning New Orleans," predicted the widespread disaster that a storm like Hurricane Katrina would impose on the city. His video *What Happens to Your Body after You Die?*, has more than 12 million views on YouTube. Fischetti has written freelance articles for the *New York Times, Sports Illustrated, Smithsonian, Technology Review, Fast Company,* and many others. He co-authored the book *Weaving the Web* with Tim Berners-Lee, inventor of the World Wide Web, which tells the real story of how the Web was created. He also co-authored *The New Killer Diseases* with microbiologist Elinor Levy. Fischetti is a former managing editor of *IEEE Spectrum Magazine* and of *Family Business Magazine*. He has a physics degree and has twice served as the Attaway Fellow in Civic Culture at Centenary College of Louisiana, which awarded him an honorary doctorate. In 2021 he received the American Geophysical Union's Robert C. Cowen Award for Sustained Achievement in Science Journalism, which celebrates a career of outstanding reporting on the Earth and space sciences. He has appeared on NBC's Meet the Press, CNN, the History Channel, NPR News and many news radio stations. Follow Fischetti on X (formerly Twitter) @markfischetti

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Materials Science

- **How to Make Alien Ice**
  Tricks to produce strange “ordered” ice could reveal new ice forms

How to Make Alien Ice

Tricks to produce strange “ordered” ice could reveal new ice forms

By Elise Cutts

Thomas Fuchs

Most solids owe their solidity to the regular, latticelike arrangements of their molecules and atoms. But in the water ice that falls as snow or crusts over windows on frosty mornings, only the oxygen atoms are orderly; H_2O’s two Hs can orient any which way.

Ordered ices, whose hydrogen atoms are neatly organized instead, most likely exist elsewhere in the universe, such as within the high-pressure hearts of gas giants and icy moons. Studying these exotic ices in the laboratory is tricky because they form so slowly. But in experiments with an ice called ice XIV, scientists publishing in *PNAS Nexus* have discovered tricks for creating ordered ices up to 100 times faster than before—within days rather than years.

“The results are really clear and very, very helpful,” says condensed matter physicist Leonardo del Rosso of the National

Research Council (CNR-IFAC) in Florence, Italy, who also studies ordered ice. “This strategy is applied to ice XIV, but you can extend these to other forms of ice—I hope!”

Ice XIV forms at low temperatures and extreme pressures (about 10 times the pressure at the bottom of the Pacific Ocean’s Mariana Trench), and its molecules form DNA-like double helices. Stranger still, a glacier made of ice XIV, or any ordered ice, wouldn’t flow; instead it would shatter. Study lead author Christina Tonauer, a physical chemist who performed the experiments as a graduate student at the University of Innsbruck in Austria, says she can feel this textural difference when she grinds samples by hand.

Ordered ice forms slowly, even under the right conditions, because hydrogen atoms get stuck and can’t move past one another. This geometric frustration is even worse in ices made of heavy water, whose hydrogen atoms have a neutron as well as a proton—a problem for scientists who use heavy ices in experiments to reveal ice crystals’ precise structures.

The researchers got around this problem by “doping” ice with small amounts of other chemicals to create gaps in the crystal lattice. These defects give hydrogen atoms more wiggle room to rearrange into ordered structures. For heavy ices, the team showed that also introducing just a tiny bit of ordinary water can

dramatically boost ordering—a “really innovative” strategy, says crystallographer Kazuki Komatsu of the University of Tokyo.

This new strategy let Tonauer’s team create heavy ice XIV quickly and, because of that speed, about three times more orderly than before. Producing such pure samples, especially from heavy water, could make it easier to discover entirely new kinds of ice and to recognize them out in the universe.

“We were just not able to reach that highly ordered state before,” Tonauer says. “Now we are able to access it in a lab day.”

Elise Cutts is a freelance science journalist who covers the earth and life sciences.

Mathematics

- **This Nomadic Eccentric Was the Most Prolific Mathematician in History**
  The bizarre life and legacy of Paul Erdős, the most prolific mathematician ever

This Nomadic Eccentric Was the Most Prolific Mathematician in History

The bizarre life and legacy of Paul Erdős, the most prolific mathematician ever

By Jack Murtagh

Paul Erdős (*left*) with his colleagues Arthur Herald Stone and Shizuo Kakutani.
New York Daily News Archive/NY Daily News via Getty Images

The doorbell rings, and you're surprised to find your colleague on the stoop. He's slight, elderly, buzzing from amphetamines, unkempt and uninvited. He shoulders past you into your living room, a single suitcase containing all of his worldly possessions in tow, and declares, "My brain is open." You have no idea how long he intends to stay because he doesn't have a house of his own to return to. You're expected to do his laundry and cook his meals because he can't be bothered to learn to take care of himself. In exchange, you'll receive a sleepless, whirlwind encounter, communing with one of the greatest mathematical minds of the 20th century. Your involuntary hospitality will probably result in an

academic publication with your name on it. This was many people's experience of Paul Erdős, the most prolific mathematician of all time.

Erdős (pronounced "air-duhsh"—the mark on the "ő" is a Hungarian double acute accent, not an umlaut) was born in Budapest in 1913 to two high school math teachers. He was a pampered prodigy. By age four he could calculate in his head how many seconds a person had been alive, and at age 21 he buttered his own bread for the first time. That same year he earned his Ph.D. in math. His subsequent fellowship position at Princeton University was cut short because, according to *The Man Who Loved Only Numbers*, Paul Hoffman's biography of Erdős, his colleagues there "found him uncouth and unconventional." Thus began his nomadic life, in which he flitted among brief academic stints, conferences and friends' guest rooms. As he would say, "Another roof, another proof."

Erdős was a notoriously bad house-guest. In Hoffman's book, mathematician Michael Jacobson of the University of Colorado Denver recounts a story in which Erdős came to his home, and they worked on math until 1:00 A.M., when Jacobson finally succumbed to exhaustion. Erdős, who tended to put in 19-hour days, stayed up and, at 4:30 A.M., banged pots in the kitchen incessantly to wake up his host. Jacobson eventually teetered downstairs in his bathrobe. He described the ensuing interaction with his colleague to Hoffman: "What were the first words out of his mouth? Not 'Good morning' or 'How'd you sleep?' but 'Let n be an integer.'"

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Erdős's single-minded obsession with math led to his authorship of a whopping 1,500-plus academic publications, more than any other mathematician in history. Quick aside: some contend that 18th-century mathematician Leonhard Euler was the most prolific of all time. Indeed, Euler produced more pages of math, whereas Erdős produced more papers. So who holds the crown depends on the unit of measure, but there is no controversy about these men being the two top contenders.

One of Erdős's most notable contributions was to something called the probabilistic method. To understand its value, imagine that you're planning a mixer for 100 people, and because mixers work best when some partygoers already know one another and some don't, you want to guarantee that no six guests in any grouping are all friends or all strangers. Is that even possible? If you try to prevent groups of strangers by inviting many friends, then it becomes harder to avoid cliques of friends, yet too many strangers will yield the opposite problem.

Mathematicians often want to prove the existence of a thing with certain properties, such as our desired party of 100 people. A natural way to do it would be to give an explicit example of such a thing (for instance, come up with a guest list with no groups of six mutual friends or strangers). This task may be quite difficult in practice, however.

Instead Erdős pioneered an ingenious alternative. He suggested that rather than trying to design the guest list by hand, you should just pick 100 names (or whatever type of object you're trying to find) completely at random. Then change your question to: What is the probability that my randomly chosen object has my desired properties? If you can prove that the probability is anything greater

than zero, then voilà! Your object must exist; if it didn't, the probability would be zero.

Changing the question to one about probability often makes it easier to answer. That's in part because you can now apply a rich set of tools from probability theory. Interestingly, because the probabilistic method circumvents the need to construct your object, you often end up knowing that something exists without a clue about what it looks like. Erdős cracked many stubborn math problems with the probabilistic method, including a more general version of our mixer problem. Today the method is considered an essential technique in every researcher's tool kit.

Much of Erdős's success sprang from his belief in math as a social activity. He had so many collaborators that the field invented the Erdős number, a measure of authorship distance from Paul Erdős, which serves as a badge of honor for scholars. Everyone with whom Erdős co-authored a paper has an Erdős number of one, all of their co-authors have a two, and so on. You might have heard of the Bacon number, an actor's co-starring distance from Kevin Bacon, but Erdős's recognition as the center of his network predates Bacon's by 25 years.

Researchers have devoted a surprising amount of effort to investigating the Erdős number, both as a lightweight amusement and as a serious tool for understanding connectivity patterns in authorship networks. Here are some curious facts about it:

- Among the more than 250,000 mathematicians who share an authorship chain with Erdős, the median number of hops required to reach him is five. (I'm proud to have an Erdős number of three.)

- Many prominent figures beyond math have Erdős numbers: Noam Chomsky (four), Angela Merkel (five), Stephen Hawking (four) and Elon Musk (four), for example.

- If one is in a playful mood, it might be argued that Baseball Hall of Famer Hank Aaron has an Erdős number of one because the two men signed the same baseball when they received honorary degrees together from Emory University.

- Actor Natalie Portman boasts the rare distinction of having an Erdős number (five) and a Bacon number (two) because of her neuroscience publication as an undergraduate (written under her birth name, Natalie Hershlag).

- Someone once tried to sell an Erdős number on eBay. The winner would have gotten to collaborate with the seller, whose Erdős number was four. Several people placed substantial bids, but the auction was snagged at the last second for $1,031 by a mathematician with no intention of paying up, who called the stunt a “mockery” of the system.

Erdős’s legacy lives on not just through his publications but in the many conjectures he left behind. Sometimes the hardest thing in math is asking the right questions, and he had a keen talent for pinpointing important problems. He issued personal monetary prizes for solutions to many problems despite having little of his own money. What he collected through speaking fees, awards and part-time appointments he typically donated to unhoused people, charities and aspiring researchers. He once gave $1,000 to a talented high school student struggling to meet tuition for Harvard University. Ten years later that student felt ready to pay the money back, but Erdős instead insisted, “Do with the $1,000 what I did.”

Paul Erdős was a man devoted to exactly one thing. He never married or had children—in fact, he was celibate his entire life. He had very few hobbies, didn’t drive, and didn’t have a permanent residence or a steady job. Erdős died in 1996 at the age of 83 at a math conference in Warsaw. He died doing what he loved, largely because he never did anything else.

Jack Murtagh is a freelance math writer and puzzle creator. He writes a column on mathematical curiosities for *Scientific American* and creates daily puzzles for the Morning Brew newsletter. He holds a Ph.D. in theoretical computer science from Harvard University. Follow Jack on X @JackPMurtagh

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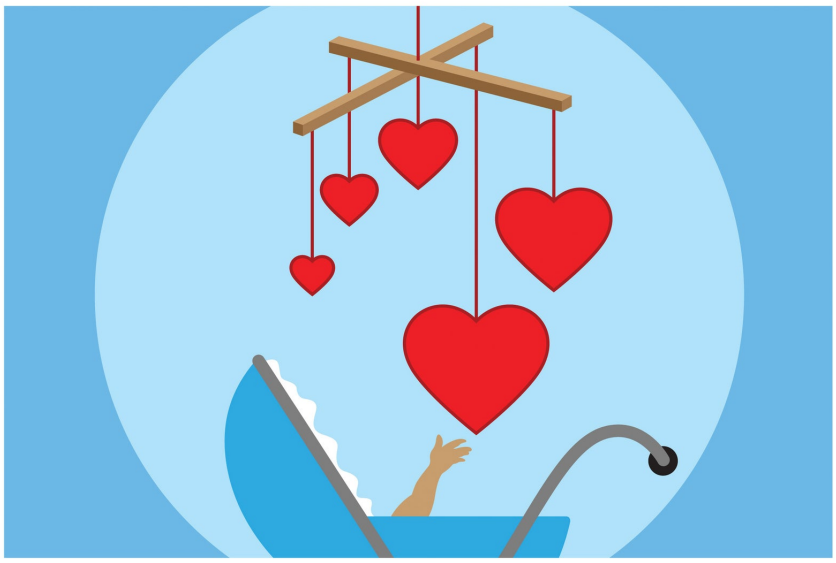
Medicine

- **Partial Heart Transplants Grow with Their Young Recipients**
  A heart valve transplant could save the life of a baby—or two

Partial Heart Transplants Grow with Their Young Recipients

A heart valve transplant could save the life of a baby—or two

By Tanya Lewis



Thomas Fuchs

Children who are born with heart valve defects often undergo surgery to receive frozen valves from cadavers. Because thawed cadaver tissue is dead and doesn’t grow, however, the child must periodically have operations to get larger valves—which can lead to a poor prognosis. But in a new procedure known as a partial heart transplant, living valves and parts of blood vessels can be transplanted and grow along with a child.

In 2022 a newborn named Owen Monroe became the first infant to receive such a transplant from a brain-dead newborn donor. Owen was born with a rare condition called truncus arteriosus: he had only one blood vessel coming out of his heart and one corresponding “truncal” valve, instead of the usual two. This defect causes oxygen rich and oxygen-poor blood to mix, which in turn

makes blood pool in the lungs and requires the heart to work harder. Plus, Owen's existing truncal valve was too leaky for him to survive with. Doctors replaced the valve (and associated blood vessel) with part of a donor aorta and valve, as well as part of a pulmonary artery and valve.

Owen's transplant was functioning well a year after the procedure, according to a new report in *JAMA* from Joseph W. Turek, chief of pediatric cardiac surgery at Duke Health, and his colleagues. "As he grows, the valves are proportionately growing. The valves function perfectly,"says Turek, who performed the surgery, adding that Owen is "meeting all of his milestones." They also found that Owen had not suffered any immune rejection.

Like any transplant recipient, Owen receives medications that prevent his immune system from rejecting the foreign tissue. But these drugs have risks, so Turek and his colleagues aimed to use the lowest dose possible. Around Owen's first birthday, they were able to reduce his medications to just one—at half the initial dose. "Immunosuppressing a kid is not without risk," says Jennie Kwon, a resident in cardiac surgery at the Medical University of South Carolina, who conducted some of the research that led to the new study. But given that these valves don't have much blood supply, researchers hope immune cells can't get to them as easily—meaning recipients won't need as much immunosuppression. "Just to get a year out [with the transplanted valves], I think, is a great win," Kwon says.

A dozen such transplants have since been performed in the U.S., Turek says. Last May doctors at NewYork-Presbyterian Morgan Stanley Children's Hospital performed the first "domino" partial heart transplant in infants: they transplanted a complete donor heart into one baby who needed a new heart muscle and then immediately transplanted that baby's original heart valves into another infant, saving two lives at once.

“This is the first study that shows that the valves are at least growing, which is huge,” says Andrew B. Goldstone, a pediatric heart surgeon who helped to perform the domino transplant. But he cautions that it’s “still very early days.”

The biggest remaining challenges, Goldstone and others say, are logistical and regulatory. There’s currently no established system for matching valve donors and recipients or for monitoring how well recipients do afterward. But Turek hopes that the procedure will ultimately benefit many more children. “I look at it as wonderful stewardship of precious organs,” he says. “We’re just trying to help as many babies as we can.”

Tanya Lewis is a senior editor covering health and medicine at *Scientific American*. She writes and edits stories for the website and print magazine on topics ranging from COVID to organ transplants. She also appears on *Scientific American*'s podcast *Science, Quickly* and writes *Scientific American*'s weekly Health & Biology newsletter. She has held a number of positions over her seven years at *Scientific American,* including health editor, assistant news editor and associate editor at *Scientific American Mind*. Previously, she has written for outlets that include *Insider, Wired, Science News,* and others. She has a degree in biomedical engineering from Brown University and one in science communication from the University of California, Santa Cruz. Follow her on X @tanyalewis314 and Bluesky @tanyalewis.bsky.social

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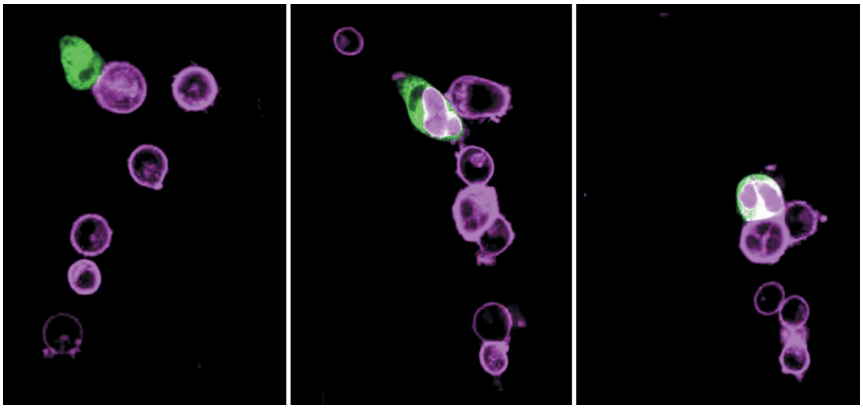
Microbiology

- **Cannibal Cells Inspire Cancer Treatment Improvement**
  Giving cells an appetite for cancer could enhance treatments

Cannibal Cells Inspire Cancer Treatment Improvement

Giving cells an appetite for cancer could enhance treatments

By Kate Graham-Shaw



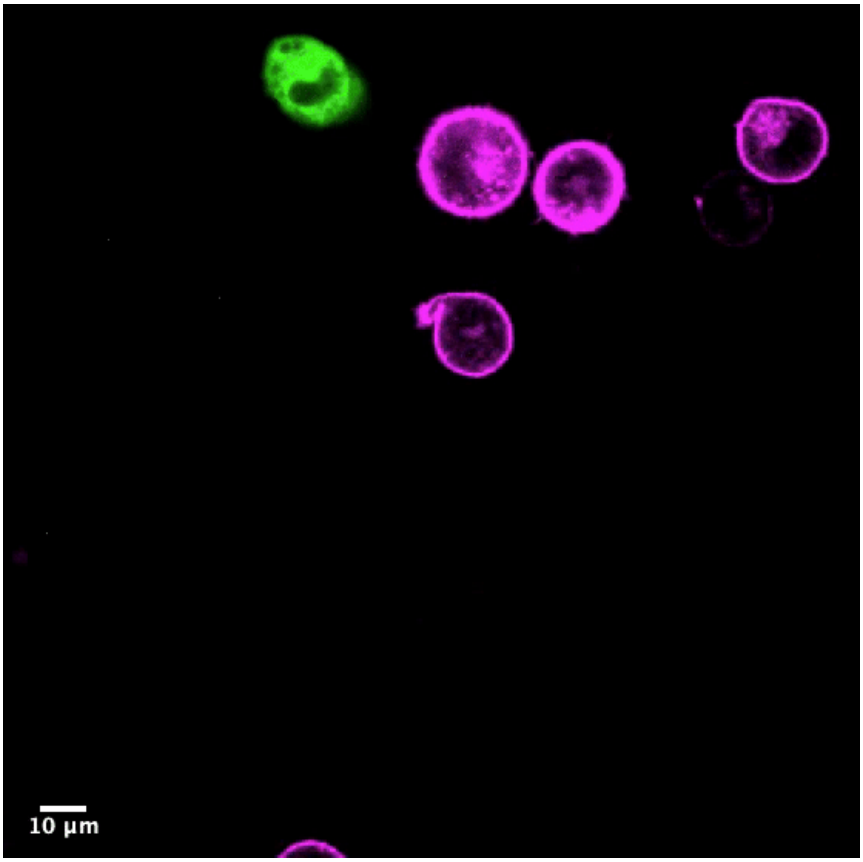
Macrophage (*green*) consuming cancer cells.
From “Hyperactive Rac Stimulates Cannibalism of Living Target Cells and Enhances CAR-M-Mediated Cancer Cell Killing,” by Abhinava K. Mishra et al., in *Cell Biology*; December, 2023.

In living organisms, some cells ruthlessly gobble up others. This “cellular cannibalism” is a common natural process: within your own body, white blood cells are consuming millions of old red blood cells this second. New research published in the *Proceedings of the National Academy of Sciences USA* suggests that using a group of genes to stimulate such cannibalistic behavior could improve a novel cancer immunotherapy.

The idea started when biologist Denise J. Montell, senior author of the new paper, and her colleagues noticed that hyperactivated forms of genes in the Rac family, which help cells envelop things they’re attempting to ingest, were causing tissue death in fruit fly embryos. It turned out that the modified genes make cells consume their neighbors in “a feeding frenzy,” Montell says. Humans have their own versions of these genes, called *RAC*, and Montell wondered whether they might help her new colleague Meghan

Morrissey at the University of California, Santa Barbara, with her work on the cancer immunotherapy CAR-M.

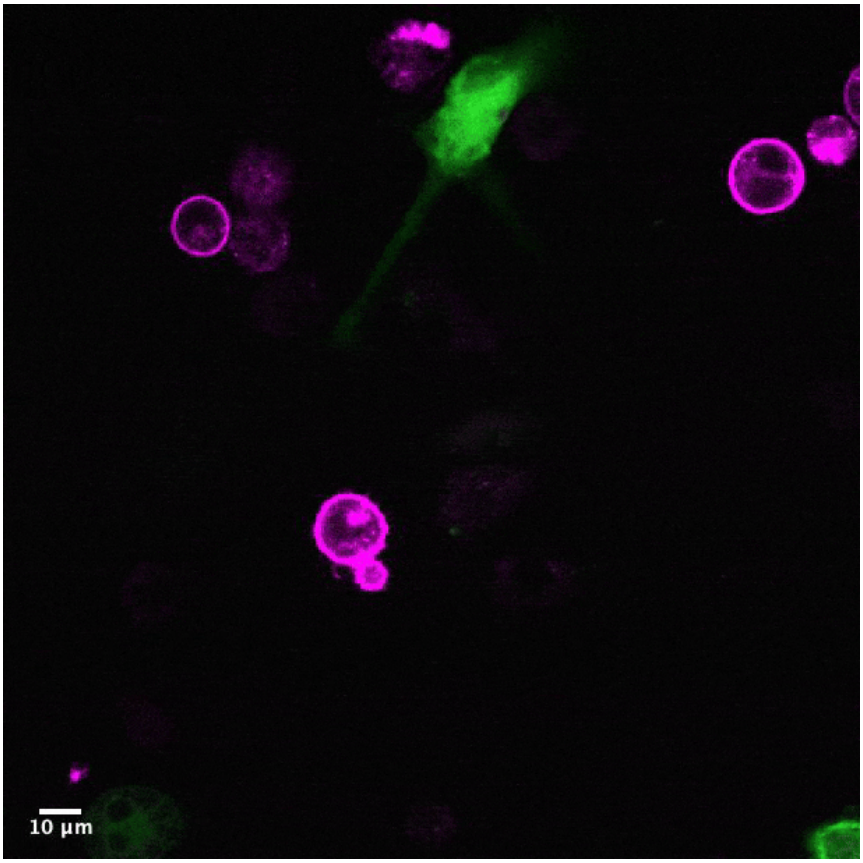
CAR-M, which is currently in early-stage human trials, focuses on macrophages: white blood cells that naturally engulf harmful substances but are typically useless against cancers. CAR-M involves collecting a patient's macrophages (M) and genetically engineering them to add proteins called chimeric antigen receptors (CAR), which let the macrophages recognize cancer cells. The macrophages are then put back into the patient, where the engineered cells should hunt down and consume cancers. A related immunotherapy already in use is most effective for blood cancers; researchers hope CAR-M will be able to target solid tumors, such as breast or lung cancers. Morrissey's research was promising, but she'd observed that many macrophages were only "nibbling" at cancer cells. Montell suspected they could use *RAC* to give the cells a heartier appetite.



Credit: From “Hyperactive Rac Stimulates Cannibalism of Living Target Cells and Enhances CAR-M-Mediated Cancer Cell Killing,” by Abhinava K. Mishra et al., in *Cell Biology*; December, 2023.

In the new study, Montell, Morrissey and their colleagues found that—at least in the laboratory—hyperactivating *RAC* genes in macrophages did indeed make them ravenous for human cancer cells. The team is now discussing collaborations with biotech companies to test these findings in larger tissues and in mice with tumors. Montell is hopeful that if those experiments work, testing could “move from mice to people relatively quickly.”

“This is certainly a really exciting translation between an observation of basic biology and applying it to how you could engineer a mammalian immune cell,” says Nathan Singh, an oncologist at Washington University School of Medicine in St. Louis, who specializes in CAR immunotherapy research. One crucial part of animal trials will be making sure the macrophages consume only tumors, he adds: “Showing that it does this in a tissue-specific way will, of course, be critical.”



Credit: From “Hyperactive Rac Stimulates Cannibalism of Living Target Cells and Enhances CAR-M-Mediated Cancer Cell Killing,” by Abhinava K. Mishra et al., in *Cell Biology*; December, 2023.

Kate Graham-Shaw is a journalist based in New York City. She covers international news for Japanese media and also covers health and science topics as a freelancer.

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Planetary Science

- ## Orion’s Twin Rogue Planets Inexplicably Blaze with Intense Radio Waves

  Researchers don’t know how this pair of free-floating planets formed or why it radiates so brightly

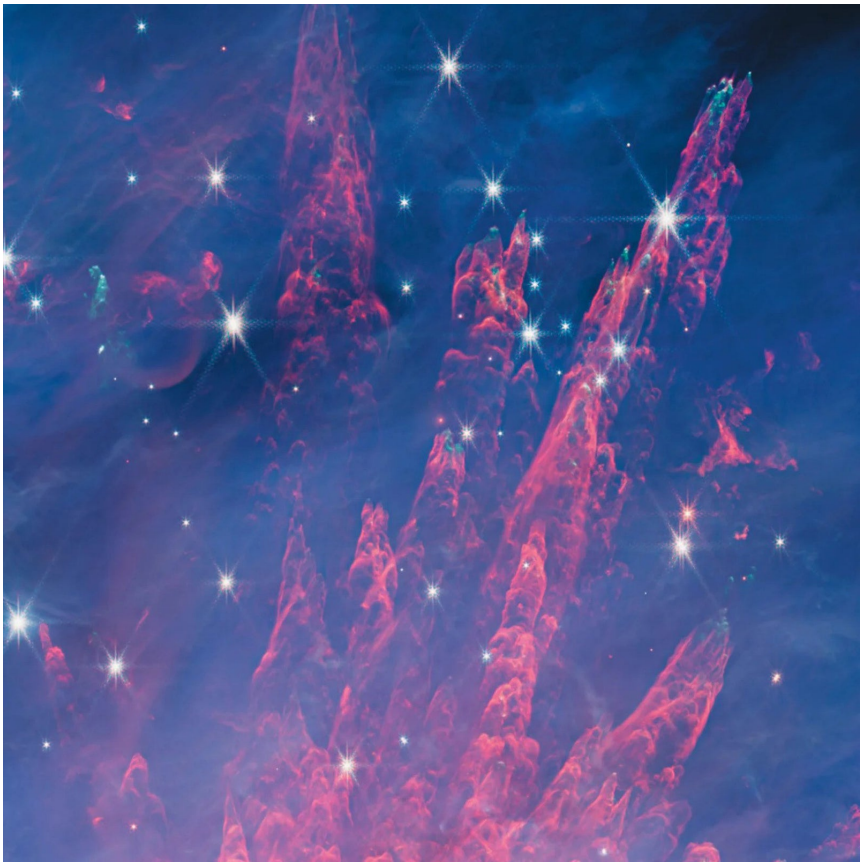
- ## See Every Bit of Outer Space We’ve Brought Back to Earth

  Sample-return missions have brought piles of moon rocks, plus pieces of asteroids, comets and even the sun back to Earth. Next up is the big prize: Mars

Orion’s Twin Rogue Planets Inexplicably Blaze with Intense Radio Waves

Researchers don’t know how this pair of free-floating planets formed or why it radiates so brightly

By Joseph Howlett



Part of the Orion Nebula shown in infrared.
NASA, ESA, CSA/Science leads and image processing: M. McCaughrean, S. Pearson (CC BY-SA 3.0 IGO)

Strange, twirling duos of roughly Jupiter-size celestial bodies in the Orion Nebula have had astronomers scratching their heads since the James Webb Space Telescope (JWST) photographed them in October 2023. Unless they were violently ejected from a solar system—unlikely, given their delicate, undisturbed dance—the free-floating pairs challenge astronomers’ long-standing notion that planets can form only within a star’s orbit.

Researchers have now discovered radio-wavelength signals from one of these 42so-called Jupiter-mass binary objects (JuMBOs), according to a study in the *Astrophysical Journal Letters*, suggesting the pair is astoundingly bright. “It’s important to understand what these objects are, and having radio data really adds a new dimension to the problem,” says the study’s lead author, Luis F. Rodríguez, an astronomer at the National Autonomous University of Mexico.

When Rodríguez and his team heard about JWST’s discovery, they scoured public telescope data for unidentified radio-wave sources in Orion and found one that recurred three times over a decade in the exact same position as the pair known as JuMBO24. The signals suggest JuMBO24 isn’t moving quickly through the nebula, which would mean it might have indeed been born alone rather than blasted away from a star system.

“The Orion Nebula is just so far away that I would never have expected there to be detectable radio emission,” says Melodie Kao, a planetary radio expert at the University of California, Santa Cruz, who was not part of the team. Large planets’ magnetic fields can capture electrons, building up a carousel of electricity that zips around their equators and beams out radio waves like an antenna. But it would take unprecedented power for JuMBO24’s signal to reach Earth. “This JuMBO would have to be extraordinarily bright—100 times brighter than anything we’ve ever seen,” Kao says. If

confirmed, this attribute would make JuMBOs even more baffling because no ordinary planet's magnetic field can sustain such a dazzling glow.

"I don't think the last word has been spoken on this, but it's a really intriguing paper," says Jan Forbrich, an astronomer at the University of Hertfordshire in England. Forbrich was not involved in this study, but his 2012 discovery of the then unidentified radio source in Orion made it possible. Both he and Kao hope to see further radio surveys of this and other JuMBOs to confirm their status as powerful radio sources.

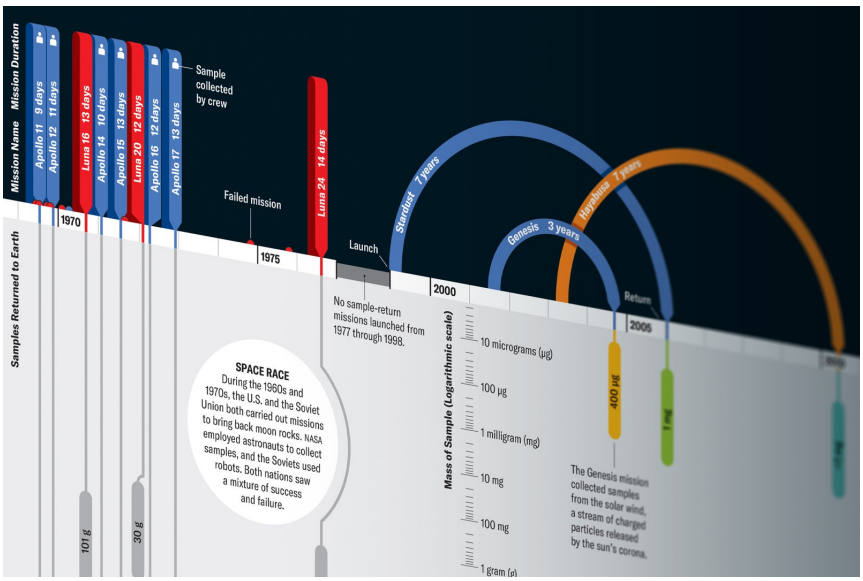
Rodríguez agrees that more radio telescopes should tune in to Orion's station. He says JuMBOs may add to our understanding of where planets come from and how many there are. If such pairs can really form without a host star, he says, "it means there are probably a zillion planets in our own galaxy that we haven't accounted for."

Joseph Howlett is a postdoctoral physicist at Stanford University. While working toward his Ph.D. at Columbia University, he participated in a collaboration searching for dark matter with a large underground detector.

See Every Bit of Outer Space We've Brought Back to Earth

Sample-return missions have brought piles of moon rocks, plus pieces of asteroids, comets and even the sun back to Earth. Next up is the big prize: Mars

By Clara Moskowitz & John Knight

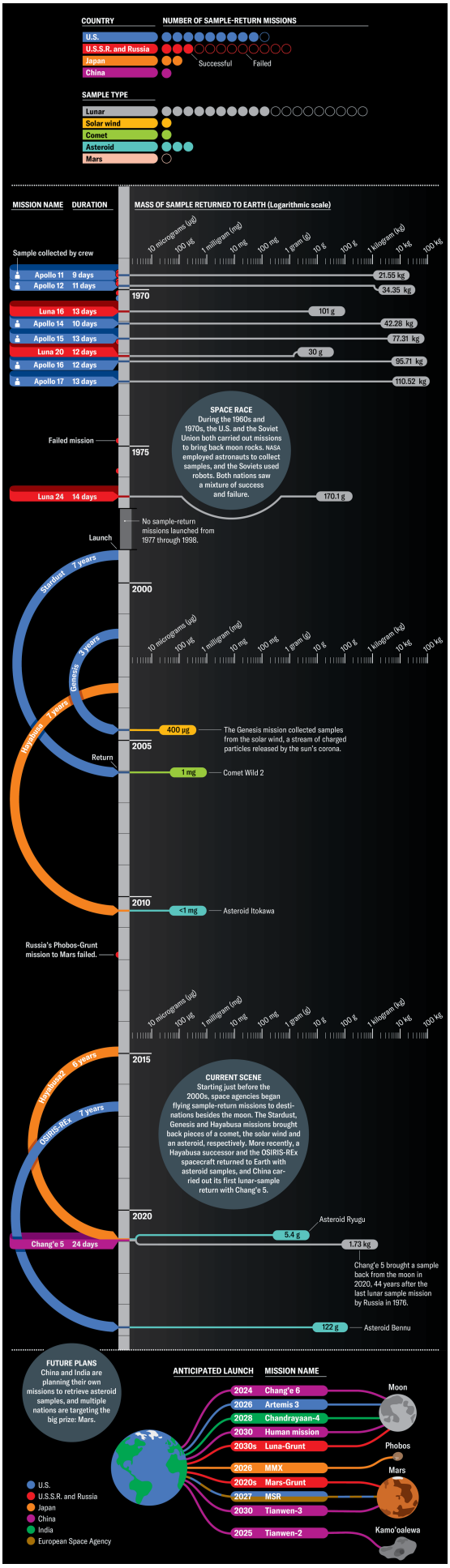


John Knight

Visiting moons, asteroids and planets is great, but taking a piece of them home is even better, according to traditional space wisdom. Bringing samples to Earth allows scientists to study them with the full breadth of existing laboratory technology, whereas only limited analyses are possible on other worlds. Yet retrieving samples from such locations requires not just getting there but launching off the surface and getting home, too. "It's hard to do, and as a result, it hasn't been done very often," says space historian Roger Launius.

Although humans have sent 10 successful landers to Mars, no one has yet brought bits of Mars to Earth. That could change in the coming decade, though, as NASA and space agencies in Europe,

China, Russia and Japan have proposals in the works to achieve this milestone. NASA's Perseverance rover has already collected samples on the Red Planet in preparation for a future retrieval mission.


COUNTRY
NUMBER OF SAMPLE-RETURN MISSIONS
U.S.
U.S.S.R. and Russia
Japan
China
Successful
Failed
SAMPLE TYPE
Lunar
Solar wind
Comet
Asteroid
Mars
MISSION NAME
DURATION
MASS OF SAMPLE RETURNED TO EARTH (Logarithmic scale)
10 micrograms (µg)
100 µg
1 milligram (mg)
10 mg
100 mg
1 gram (g)
10 g
100 g
1 kilogram (kg)
10 kg
100 kg
Sample collected by crew
Apollo 11 9 days
Apollo 12 11 days
21.55 kg
34.35 kg
1970
Luna 16 13 days
Apollo 14 10 days
Apollo 15 13 days
Luna 20 12 days
Apollo 16 12 days
Apollo 17 13 days
101 g
42.28 kg
77.31 kg
30 g
95.71 kg
110.52 kg
SPACE RACE
During the 1960s and 1970s, the U.S. and the Soviet Union both carried out missions to bring back moon rocks. NASA employed astronauts to collect samples, and the Soviets used robots. Both nations saw a mixture of success and failure.
Failed mission
1975
Luna 24 14 days
170.1 g
No sample-return missions launched from 1977 through 1998.
Launch
Stardust 7 years
2000
Genesis 3 years
Hayabusa 7 years
400 µg
The Genesis mission collected samples from the solar wind, a stream of charged particles released by the sun's corona.
Return
2005
1 mg
Comet Wild 2
2010
<1 mg
Asteroid Itokawa
Russia's Phobos-Grunt mission to Mars failed.
Hayabusa2 6 years
OSIRIS-REx 7 years
2015
CURRENT SCENE
Starting just before the 2000s, space agencies began flying sample-return missions to destinations besides the moon. The Stardust, Genesis and Hayabusa missions brought back pieces of a comet, the solar wind and an asteroid, respectively. More recently, a Hayabusa successor and the OSIRIS-REx spacecraft returned to Earth with asteroid samples, and China carried out its first lunar-sample return with Chang'e 5.
2020
Asteroid Ryugu
Chang'e 5 24 days
5.4 g
1.73 kg
Chang'e 5 brought a sample back from the moon in 2020, 44 years after the last lunar sample mission by Russia in 1976.
122 g
Asteroid Bennu
FUTURE PLANS
China and India are planning their own missions to retrieve asteroid samples, and multiple nations are targeting the big prize: Mars.
ANTICIPATED LAUNCH
MISSION NAME
2024 Chang'e 6
2026 Artemis 3
2028 Chandrayaan-4
2030 Human mission
2030s Luna-Grunt
2026 MMX
2020s Mars-Grunt
2027 MSR
2030 Tianwen-3
2025 Tianwen-2
Moon
Phobos
Mars
Kamo'oalewa
U.S.
U.S.S.R. and Russia
Japan
China
India
European Space Agency

Credit: John Knight

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Clara Moskowitz is a senior editor at *Scientific American*, where she covers astronomy, space, physics and mathematics. She has been at *Scientific American* for a decade; previously she worked at Space.com. Moskowitz has reported live from rocket launches, space shuttle liftoffs and landings, suborbital spaceflight training, mountaintop observatories, and more. She has a bachelor's degree in astronomy and physics from Wesleyan University and a graduate degree in science communication from the University of California, Santa Cruz.

John Knight is a freelance data visualization designer specializing in scientific communication. More of his work can be found at john-h-knight.com

Psychology

- **Psychology Hacks for Resisting Trash Talk**
  A new book explores the science of trash talk—and why some people are more immune to it than others

Psychology Hacks for Resisting Trash Talk

A new book explores the science of trash talk—and why some people are more immune to it than others

By Jessica Hullinger

Shideh Ghandeharizadeh

Trash talking—the act of slinging insults—is perhaps most pervasive in sports, where athletes deploy their best taunting tactics in an attempt to deflate their opponent and gain an advantage. But in *Trash Talk: The Only Book about Destroying Your Rivals That Isn't Total Garbage* (PublicAffairs, 2023), author Rafi Kohan explains that trash talk is far more than just "verbal static."

At its most basic level, Kohan says, trash talk is a language of competition. It's a ubiquitous human behavior that spans cultures, countries and centuries—a stealthy psychological tool deployed by politicians, comedians and business leaders alike. Today Donald Trump's normalization of trash talk has been correlated with spikes in hate crimes and the number of threats to sitting members of Congress in both parties.

Trash talk doesn’t have a reputation for being a particularly respectable form of communication. But Kohan thinks that landing a well-timed and expertly calculated “your mama” joke is an art form—and one that deserves a more scientific look into how it functions. *Scientific American* spoke with Kohan about what is behind the science of trash talk, why trash talk works on some people and not others, and what it can teach us about resilience in the face of stress and anxiety.

An edited transcript of the interview follows.

What do experts think might be the evolutionary roots of trash talk?

When you look at the role that trash talk plays in creating group bonds, it has very clear applications in creating a sense of “us versus them.” When you talk crap about a rival, you’re reinforcing a sense of identity. You’re reinforcing who we are and who they are. One theory about why trash talk works to throw people off their game is that it leverages a fear of social isolation, of ostracization, of being kicked out. It’s taking advantage of that deep-seated, primal fear that we’re going to be left on our own, and we’re going to die. To bring it to a biological level, trash talk is suggesting you do not have the resources to survive.

Why do verbal insults cause some people to underperform?

When you experience stress, there are two divergent physiological responses you can have: a challenge response and a threat response. In a challenge response, your heart is pumping blood to your extremities so you can take action, and your performance improves. In a threat response, your body is preparing you for a violent attack—your pulmonary vasculature constricts; your blood is sent back to your core organs—and your performance deteriorates dramatically.

So trash talk leans on these fears to try to elicit the same kind of biological response that flips people into a threat state. There's a model in sports known as individual zones of optimal functioning (IZOF). It says that everybody has a certain amount of anxiety at which they will perform at their best. This is their optimal zone of functioning, and it's different for everybody. So for certain folks who cannot handle trash talk, maybe it gives them too much anxiety, and they're exploding through the ceiling of their IZOF threshold. And when you're overwhelmed by anxiety, there's a dramatic decline in performance.

I'm tickled by the concept of polite trash talk, which is basically just saying nice things to your opponent. Why does this work?

Polite trash talk is effective simply because it is so surprising. Attention is critical to performance, and one terrific way to steal someone's attention is to do something unexpected. Something like polite trash talk or weird trash talk or even someone getting on all fours and barking like a dog, as [former National Basketball Association star] Kevin Garnett has done on the basketball court, forces our mind to slow down to process the information, and that is inherently distracting.

Complimenting someone on their shot or their serve or just congratulating them on a good play or being generally charming and asking them how their offseason has been—these things can also cause people to downregulate and relax. Former [National

Football League] offensive lineman Mark Schlereth described this as pouring honey on your opponent: you compliment them and hope they get stuck in sticky honey—[in] a state in which they're not trying as hard.

Trash talk can be detrimental to performance, but at the same time, some coaches say trash talk among players is a sign of a healthy locker room because it is a bonding mechanism. Some players seem to get a boost from it.

Intimacy can masquerade as incivility. Trash talk can be a sign that you feel comfortable around the people you're talking trash to. It can really be a prosocial, bonding endeavor. [The late] Kobe Bryant famously would talk vicious trash to his teammates. One theory posited to me by a former [Los Angeles] Lakers staffer was that he was doing it because he wanted you to push back. He needed to see that you were not just going to fold. At its core, trash talk is a kind of test. It's a way to negotiate social status and to negotiate roles on a team.

Trash talk doesn't work on everyone. What can we learn from the people who manage to let even the most personal insults roll off their back?

Even if you're having a lot of anxiety, there's a way to train yourself to bring anxiety levels down. Self-awareness and self-regulation are the foundations of developing mental toughness and staying in your zone, and a lot of it comes down to just breathing. It sounds so basic, but when you take a breath in, your arousal goes up. When you exhale, your arousal goes down. When you see a basketball player go to a free throw line or a baseball player about to throw a pitch or a tennis player about to serve the ball, and you see them take that big inhale and that even bigger exhale, they're lowering their arousal. They're lowering the anxiety in their body to get to the proper level so they can perform at their best.

Another self-regulation strategy is acceptance. You accept that someone said something mean about your dead dog or whatever it is, and you decide whether that's a useful thing for you to hold on to. Will holding on to this make me focus? Will it make me enter my zone of optimal functioning? Or is it dysfunctional for me—in which case I'm going to discard it? You're not ignoring it. You're accepting it. You say, "I'm mad," and by acknowledging it, you let the emotion dissipate. Breathe out, and it goes away. Acceptance is a big one.

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Public Health

- **AI-Optimized Catheter Design Could Prevent Urinary Tract Infections without Drugs**
  A 3D-printed tube stymies microbes with a tiny obstacle course to combat rampant infections in hospitals

AI-Optimized Catheter Design Could Prevent Urinary Tract Infections without Drugs

A 3D-printed tube stymies microbes with a tiny obstacle course to combat rampant infections in hospitals

By Joanna Thompson

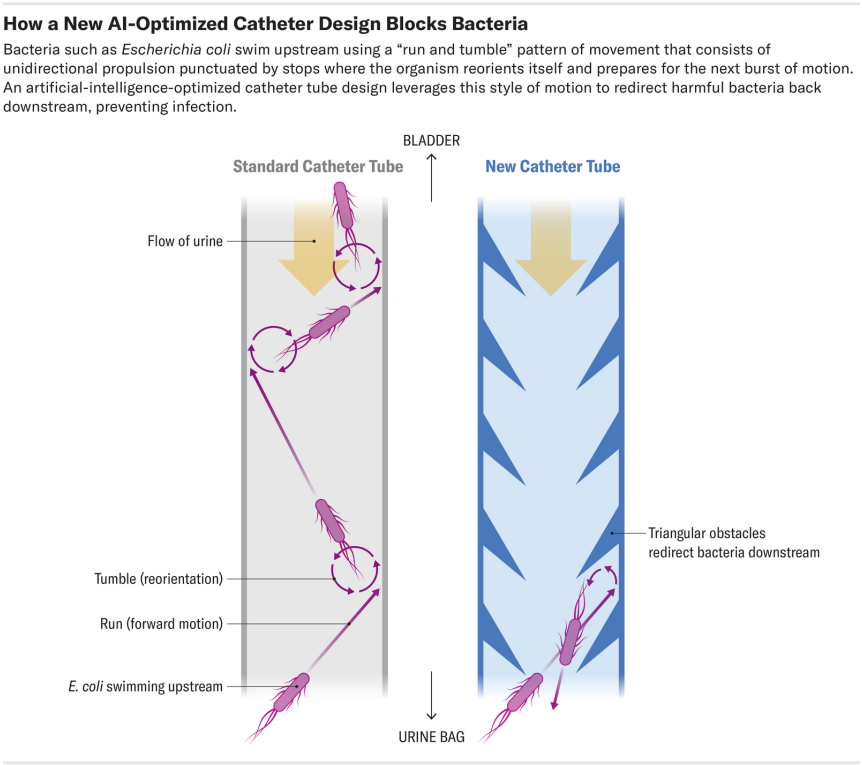
Lamp Soul Studio/Getty Images

More than 100 million urinary catheters are placed every year, and the devices can be lifesaving, especially after surgery. But many of those who use them—about a quarter of users in developing countries and about an eighth in the U.S.—develop a catheter-associated urinary tract infection (CAUTI), commonly caused by bacteria building up inside the tube.

Researchers aided by artificial intelligence have now designed a new catheter they say could reduce bacterial contamination by up to two orders of magnitude—without antibiotics. Its interior is studded with three-dimensional geometric shapes that help to prevent bacteria from gaining traction and making it to the bladder.

“In a normal catheter, there is no physical shape inside,” says computer scientist Animashree Anandkumar, co-author of the new study in Science Advances. This leaves a smooth highway for bacteria to work their way up from the outside and colonize the inner surface. When colonies build up in the catheter near the bladder, they can enter the urinary tract and lead to a CAUTI.

In the past doctors have sometimes coated catheters’ interior walls with antibiotic drugs or metallic agents such as silver to kill bacteria. But such methods can be expensive—and increasingly ineffective as antibiotic-resistant bacteria become more prevalent. The new device does not rely on a specialized coating to repel microbes; simple geometry does the trick. A series of tiny, 3-D—printed ridges shaped like sharp triangles line the inside of the catheter, forming a kind of obstacle course for the bacteria. As the microbes try to swim upstream, they bump and tumble into the ridges, eventually halting or bouncing back down. The design could help reduce expensive and unnecessary antibiotics and could prolong the amount of time a catheter can be used," the researchers say.



Credit: Amanda Montañez; Source: "AI-Aided Geometric Design of Anti-Infection Catheters," by Tingtao Zhou et al., in *Science Advances*. Published online January 3, 2024

To find the perfect bacteria-repelling labyrinth, Anandkumar and her team used AI to quickly run digitally modeled catheters through tens of thousands of simulations. Once they landed on a design that best blocked virtual bacteria under multiple scenarios in the computer model, they 3-D printed a prototype and tested it in the laboratory with a broth containing *Escherichia coli* bacteria. After 24 hours, the experimental device had built up less than one one-hundredth of the bacterial colonies in a traditional catheter that the researchers 3-D printed and tested alongside it.

"These are pretty exciting results," says Glenn Werneburg, a Cleveland Clinic urologist who was not involved in the study. He notes that the new catheter is currently optimized to resist *E. coli*—one of the most common microbes associated with CAUTIs—but other species are also known to colonize catheters and cause infection. "Bacteria on catheters are present as biofilms, and we know that different species of bacteria behave in different ways," Werneburg says. A modified future design would ideally be inaccessible to other microbes, such as *Enterococcus* and *Proteus*

bacteria, he adds. Anandkumar agrees, and she says that accurately modeling such designs may require further research and more data about these microbes' properties. The scientists will also need to test their AI-modeled design in a clinical setting before it can be widely produced.

Anandkumar says such modeling has potential far beyond catheters: she hopes to harness AI to help design drugs, energy-efficient airplane propellers, and more. "To me," she says, "this is just the beginning."

Joanna Thompson is an insect enthusiast and former *Scientific American* intern. She is based in New York City. Follow Thompson on Twitter @jojofoshosho0

Weather

- **Lava-Lit Lenticular Cloud Crowns Volcano in Spectacular Photo**
  These bizarre-looking clouds form in stable atmospheric eddies

Lava-Lit Lenticular Cloud Crowns Volcano in Spectacular Photo

These bizarre-looking clouds form in stable atmospheric eddies

By Joanna Thompson

Francisco Negroni

Villarrica is one of Chile's most active volcanoes. Its Mapuche name, Rucapillán, means "house of the spirits," and looking at it, it's not hard to see why. But that isn't some kind of otherworldly smoke ring wreathing Villarrica's crater—it's a cloud.

Lenticular clouds form when moist air flows up a mountain, volcano, or other geographic feature. These obstacles act like rocks in a stream, forcing air to travel around them in a stable, eddying pattern. As water-filled air rises into this current, it cools and condenses into visible clouds that drop after pushing over the summit, "sort of creating a wavelike motion," says Corwin Wright, an atmospheric physicist at the University of Bath in England. The result is a seemingly stationary cloud that hovers over the landscape like a flying saucer or ominous-looking ring of smoke.

In addition to creating clouds that look like an alien invasion, these eddies play a vital role in global wind circulation. For example, they act as speed bumps that help to slow the Southern Hemisphere's jet stream. "But you don't normally see them day to day," Wright says, "because obviously air is transparent."

Luckily for photographer Francisco Negroni, a lenticular cloud materialized over Villarrica when it was at its most dramatic for this award-winning shot. After the volcano entered a period of activity, Negroni camped at its snowy base for 10 days as he waited for the right moment. He then set up his camera and opened the lens for a full four minutes to capture enough light. That was enough time to track Earth's rotation, which makes stars appear as streaks of light even as the volcano's lenticular crown stays put. For Negroni, the shot was more than worth the effort. Photographing volcanoes "is my life," he says.

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