

NAUTILUS

ATOMS THE SIZE OF CITIES

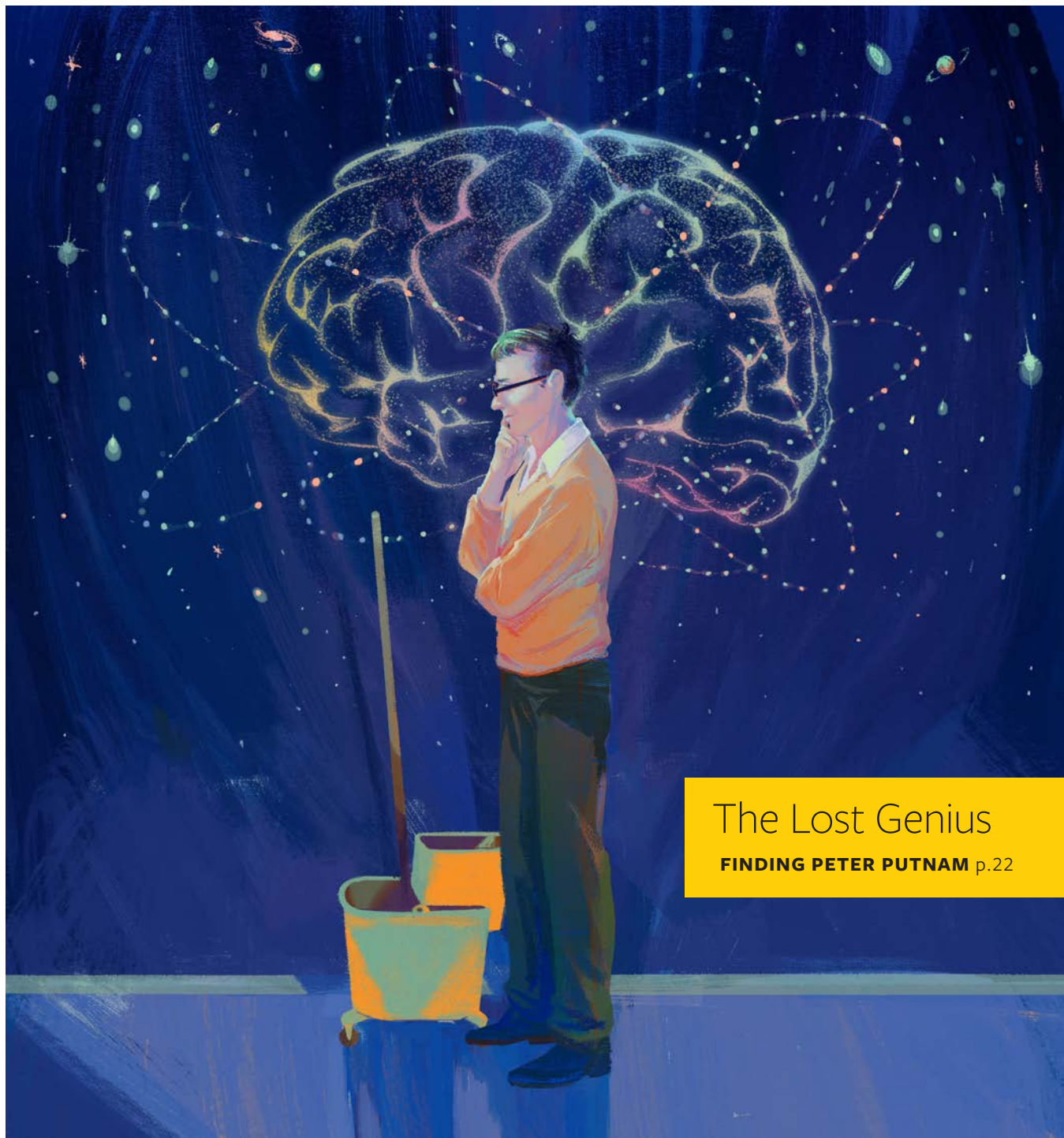
Behold the neutron star

WE ARE ONE PERSON

Why we're not as unique as we think

HOW DID I GET CANCER?

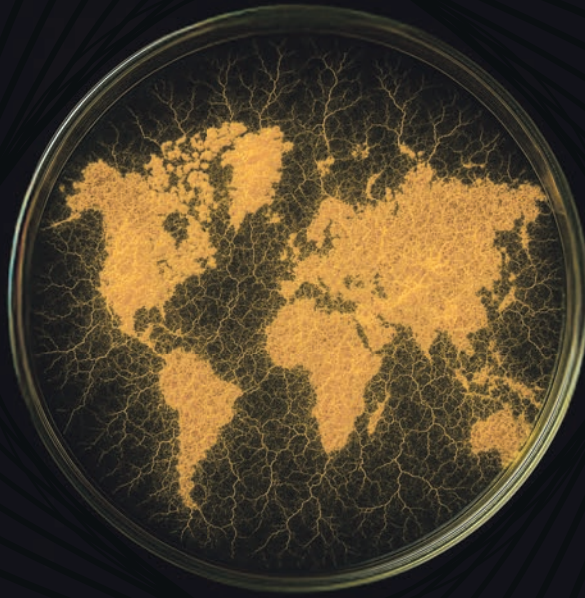
A chemist investigates her own body



The Lost Genius

FINDING PETER PUTNAM p.22

SANTA FE INSTITUTE



What if we could
Emergently Engineer
together with our Planet
instead of Engineering
the Planet?



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BOLDLY EXPLORE

OUR UNKNOWN OCEAN

R/V Falkor (too)



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NAUTILUS

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A Forgotten Mind

BY KATHERINE HARMON COURAGE

YOU HAVE NEVER HEARD of him. But after reading this issue's cover story, you won't soon forget him.

His name is Peter Putnam.

He was a beloved student of pioneering physicist John Archibald Wheeler at Princeton University, spent time with Albert Einstein and Niels Bohr, and he developed a wild, comprehensive model for how our minds work that, half a century later, is aligning with the latest research in neuroscience, and even artificial intelligence.

But until now, his writings and ideas have been stashed in attics, locked in filing cabinets, buried in archives, unpublished, in darkness.

Writer Amanda Geffer opened the boxes, the filing cabinets, dug through the storage units, read through tens of thousands of pages of nearly unintelligible theory, and has spent more than a decade deciphering and synthesizing this lost physicist's story.

"Only two or three times in my life have I met thinkers with insights so far reaching, a breadth of vision so great, and a mind so keen," Wheeler remarked in the 1990s about our protagonist.

Putnam's story, told here for the first time, gave me chills. (I had written to Geffer a year ago about a different story idea, and I will never forget her reply: "That sounds intriguing [but] ... I actually do have one other story idea that I was hoping to talk to you about—it's one I've been working on for 10 years!")

"Finding Peter Putnam" recounts the life of a mind, a man, who struggled to find his place in the world. Whose identity, family, and, in some way, prescient brilliance, kept him from joining the canonical names those who knew him placed him alongside: Alan Turing, Kurt Gödel.

One of Putnam's fellow physicists told Geffer, "Putnam really should be regarded as one of the great philosophers of the 20th century. Yet he's completely unknown." Even as a great benefactor (which he was, anonymously funding world-renowned public art and ecologically important conserved lands across the United States).

In part it's because he wrote in "Putnameese," as those who knew him called his obtuse way of communicating, and because he left academia, moved to a small town in Louisiana, and took up work as a nightwatchman and janitor.

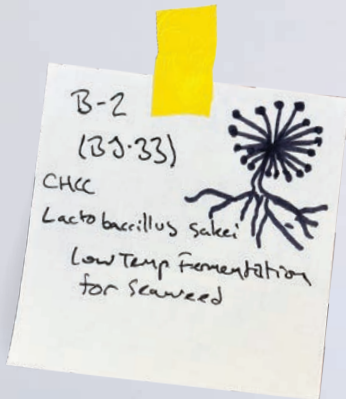
But that's not the whole story, as Geffer's magisterial profile makes clear.

She has brought a forgotten man back to life, and shows the story of his radical ideas is just beginning, here, now.

Imagine
stories →
can save
our planet

FORMER HEAD OF FERMENTATION AT LEGENDARY RESTAURANT NOMA, DAVID ZILBER IS A FOOD SCIENTIST ON A DELICIOUS MISSION: TO BUILD A BETTER FOOD SYSTEM - WITH A LITTLE HELP FROM HIS MICROSCOPIC FRIENDS.

I make
climate-friendly
foods with
microbes



David

A curved arrow points from the name 'David' to the man in the center of the image.





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HARPER'S

MAGAZINE

Findings

A mother is 4.6 percent more likely to give birth in the same month she was born.  Half of all beef consumed in the United States is eaten by 12 percent of adults.  The playing speed of a metal guitarist directly correlates with his intrasexual competitiveness but not his mating success.  Scientists advised against consuming hypersexual zombie cicadas infected with psychoactive fungus.  A metal scar on the surface of the white dwarf WD0816310 indicated that it has cannibalized other bodies in its orbit.  Dwarf rock-wallabies were found to have unusually large teeth. "If I were a vegetable," said a skull-shape researcher, "I would not mess with a pygmy rock-wallaby." 

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THE PORTHOLE

Short sharp looks at science

GENETICS

We've Got the Beat—in Our Genes

BACK WHEN I WAS A MOHAWKED teenager, my mother was horrified by the music that moved me. Dutiful flower child that she had been, merely mentioning The Dead Kennedys would cause her to weep. She had raised me on The Beatles; Peter, Paul and Mary; Bob Dylan; the soundtrack from *Hair*—and I repaid this education in free love by idolizing a band whose name made a sneering joke of one of her generation's defining cultural ruptures. Nothing could have displeased her more.

But a new study on the genetics behind our responses to music suggests that it might have been partly her fault. For, as divergent as our tastes in specific bands might have been, research from the Max Planck Institute of Psycholinguistics in Nijmegen, the Netherlands, shows that our capacity to feel moved by music is at least partly heritable.

That explains some things. While my mom might not have been a fan of *what* I was listening to—at least during my aggrieved adolescence—there was never any question in our house that music *would be* listened to. Whether the tempo was set by Joan Baez or the Sex Pistols, it was the search for the tempo itself that was fundamental—our attraction to it as immutable as our signature green eyes. And that set us apart, making our house louder than others in a neighborhood where the quest for the jam seemed less pronounced.

People like our neighbors served as a source of inspiration for cognitive neuroscientist Giacomo Bignardi, the lead author of the new study. Noticing that some



folks didn't seem to feel much from music at all, he was moved to investigate what separates them from people who are deeply affected by it—whether they dance, tear up, get chills, or are just all-around slaves to the groove.

"I got the idea that our capacity to enjoy music may be partly influenced by our genetic makeup from the curious case of musical anhedonia—a blunted capacity to feel pleasure from music, despite no major deficits in auditory, music perceptual, or general reward processing," Bignardi wrote to me in an email.

Bignardi's team used a twin study design to compare similarities between identical twins and fraternal twins. Their thinking was that if genetics do play a role in our ability to enjoy music, the musical enjoyment profiles of identical twins, who share 100 percent of their genetic material, would be more similar than those of fraternal twins, who share roughly 50 percent.



With help from the Max Planck Institute for Empirical Aesthetics in Germany and the Karolinska Institute in Sweden, the team compiled detailed genetic data and survey responses from more than 9,000 Swedish twins not only about music reward sensitivity, but also general reward sensitivity, as well as their ability to perceive musical features such as pitch, melody, and rhythm.

To drill into their enjoyment of music, the different twin groups were asked to answer questions on a standardized psychological tool called the Barcelona Music Reward Questionnaire, which has long been used to establish not only whether respondents enjoy music, but how they enjoy it and to what degree. The survey consists of 20 statements, such as “I get emotional listening to certain pieces of music,” “Music makes me bond with other people,” and “I can’t help humming or singing along to music that I like,” which respondents are asked to rate on a five-point scale: 1 for weak agreement to 5 for strong agreement. To get a sense of the twins’ musical perceptual abilities and general reward sensitivity they used separate standardized tests.

What Bignardi and his team discovered when they crunched the responses and analyzed them against the genetic data is that one’s ability to experience pleasure from listening to music is indeed partly written in our genes. Using the twin design, they estimated that about 54 percent of the variation in musical reward sensitivity could be explained by genetic differences.

Bignardi and his team also found that genetic influences related to music reward sensitivity are largely independent from those associated with reward sensitivity for other non-musical activities—the ability to enjoy cooking, or art, or French movies, for instance. They’re also mostly distinct from genes associated with musical perceptual abilities, like a talent for learning music. (Prior research has shown that numerous genetic factors play into a person’s ability to synchronize with a beat, recognize a melody, and achieve mastery of a musical instrument.)

Further, they found that the genetics of enjoying music don’t involve a single gene, but rather a cluster of them, offering confirmation to recent research

We inherit our capacity to be swept away by the sound of music.

in the field of behavioral genetics, which examines how genes act in concert. And they found that each type of musical enjoyment is genetically interconnected but distinct: In other words, specific genes may decide whether music inspires some of us to dance, but not to feel emotionally soothed by

music. Why some feel a sense of camaraderie when headbanging along with an arena full of leather-clad confrères but feel no need to rush out and perform music with a group. And why others may tap along to a familiar tune on the radio but not experience a wave of nostalgia about how that song was playing when they met their spouse.

What all these various responses have in common, though, is that they’re mostly (but not entirely) explained by genetics, with shared upbringing playing little to no role. Identical twins who grew up in very different environments, in other words, still tended to love music in similar ways, while fraternal twins did not.

“This is an interesting and well-done paper with state-of-the-art analyses and a large sample that permits these sophisticated analyses,” says Robert Plomin, a leading behavioral geneticist at King’s College London, who wasn’t involved in the study.

Plomin says the findings square with his decades-long research on the genetic basis of our psychological traits, which has shown that many human traits—from the emotional to the cognitive—are shaped by overlapping genetic forces, rather than by single genes acting alone.

“It’s striking that so much of genetic effects are general for cognitive abilities, psychopathology—and now music,” Plomin says.

That we inherit not just our eye color or temperament but also our capacity to be swept away by the sound of music would appear to show just how deeply the search for the groove seems to be wired into many of us. It’s not just a cultural artifact or a learned habit—it’s a biological response, shaped by evolution, refined by personality, and—yes—handed down through family lines.

Bignardi told me he wants to keep pushing on his search for the origins of music loving.



“Where *does* the capacity to enjoy music come from?” he wrote me. “I think we are still very far away from having a satisfactory answer to this question. To be honest, I am not sure whether we have a satisfactory question to begin with.”

“For some, [music] seems to be a necessity,” he continued. “For others, it doesn’t. To me, that is what matters the most.”

He and his team also want to see future studies that focus more closely on the individual facets of musical enjoyment—investigating, for instance, who gets

chills, who feels social, who headbangs, who is moved to tears, and why.

I eventually outgrew my mohawk—though it would dismay my mother to know that my affection for the Dead Kennedys has proved more durable. But Bignardi’s study assured me that this actually makes my mom and me much closer than our tastes might suggest. In the end, we were doing the same thing: reaching instinctively for music, because some part of us was built for it.

—Charles Digges



HISTORY

A Truer Story of Native America

A **BRILLIANT SUPERNOVA** visible across North America and much of the rest of the world in the 11th century is said to have inspired an explosion of civilization building among Indigenous cultures across the Mississippi Valley and the American Southeast. One of the grandest cities was named Cahokia, which sprung up near what is now St. Louis. Cahokia had a plaza the size of 30 football fields and earthen pyramids up to 100 feet tall, and it quickly

swelled to become the largest pre-Columbian settlement north of Mexico: The city’s peak population of more than 10,000 rivaled London’s at the time. But it was just one of many Native American metropolises. The Huhugam people’s sprawling civilization in the Southwest, for example, contained more than 1,000 miles of canals.

These cities were abandoned by the late 14th century amid climate change and political instability, an exodus that many European settlers perceived as



signs of the civilizations' declines, according to written accounts. But in reality, many of the Indigenous peoples left their cities in a purposeful way, to create more egalitarian and sustainable societies, according to recent scholarship from historian and author Kathleen DuVal. And these Native societies continued to make up the majority of the North American population through the mid 1700s and to control most of the land and resources on the continent for a century after that, says DuVal. Her findings contradict myths perpetuated by white settlers and historians for centuries—namely, that Native influence had greatly declined by the 19th century, and that Native populations lacked advanced civilizations.

DuVal outlines these arguments in her 2024 book, *Native Nations: A Millennium in North America*, which recently won a Pulitzer prize. A professor at the University of North Carolina at Chapel Hill, DuVal specializes in early American history and her work aims to amplify the voices that are often overlooked in historical accounts, including enslaved and Indigenous people, and to connect their narratives with the present. When preparing *Native Nations*, DuVal took care to work closely with Native American historians and scholars to ensure fidelity to their own accounts of their history. Many other historians of North America's colonial period have relied primarily on texts and sources from white colonial settlers, though this emphasis is shifting.

Nautilus spoke with DuVal about how her work rewrites the history of North America, her efforts to foreground Native scholarship, and what lessons the story of Indigenous retreat from cosmopolitan cities has for today.

Your book is described as reshaping the history of the North American continent. How does it do that?

This book takes a long view. It's 1,000 years of history, and that puts the United States in context—the U.S. has been here for just about 250 years. Native nations have been here for millennia, and they're still here today within the United States, Canada, and Mexico. That longer timespan helps us both to realize that the United States and the things the country has done were not inevitable, and that they are only a small part of Native American history.

There was an intentional forgetting in the late 19th century and early 20th century.

You note that most of North America remained under Native control into the 19th century. Why has this history gotten lost in modern retellings?

There was an intentional forgetting in the late 19th century and early 20th century, when white Americans told themselves that this continent really didn't belong to Native Americans, that there weren't that many of them, and they weren't that organized. I think that was part of coming to grips with the fact that the United States did some really terrible things—forced people off of their land and fought some brutal wars against Native Americans. It was easier to believe that Native Americans had never really been important for white Americans to ease their consciences.

What might what is now the United States look like if, as you wrote, "British colonists could have lived side-by-side with Native nations, continuing to ally and trade in mutually beneficial ways?"

It would have looked more like what people imagined before the 19th century. It wouldn't just be one country—it would be multiple countries. There would be Native nations with their own territory and sovereignty, completely separate from but maybe allied with other Native nations. Maybe some countries that were multiple Native nations coming together, but it wouldn't be all one country.

This book traces the embrace and then rejection of urban life by Native American groups and their transition to less centralized communities. Can we take lessons from these decisions today, particularly given your observations of these Native societies' climate-driven struggles with agriculture and the hoarding of wealth by Native elites?

It tells us there's a different way to organize societies. These societies were more democratic and egalitarian than Western European societies at the time, or than the United States that was created. There are different



kinds of ways to live on the land and in a community. These nations were smaller-scale than the United States, but I think at least locally, on a county and state level, there are ways we can now imagine having values that mirror that focus on reciprocity.

You have long worked to highlight marginalized voices in early America and offer a perspective outside of the colonial outlook. Is it challenging to find primary sources?

It is less difficult than I thought it would be to find many different kinds of voices from the past. Looking at the 17th and 18th centuries, almost everybody who was writing things down were white men. But those white men also recorded what Indigenous people said to them. It's clear from those records that the white writers knew that these Indigenous people mattered and had power, even when the writers didn't like the things they were trying to do. For example, in the 17th and 18th centuries, French and Spanish officials who were sent out to Quapaw country, in what's now Arkansas, wrote back reports to their superiors in Paris and Spain. They wrote down long speeches that Quapaw chiefs gave to them and described what was going on with the Quapaws and the people they were fighting against. These records aren't perfect: They don't come directly from Quapaws, but tell us a huge amount about what they were doing and what mattered to them at the time.

You made a special effort to foreground Native perspectives and scholarships in this book. What do these perspectives bring to the work that you could not provide yourself as a non-Native researcher?

There are almost 600 federally recognized tribes in the United States, and many more state-recognized tribes. I couldn't possibly be an expert in the histories of all of them—much less what's happening in the present day. One of the things this book tries to do is to connect the present with the past, so it's been important to talk to scholars within tribes today who are doing things like working on language and reviving various parts of material culture, who have kept their own histories. For example, the linguistic work the Quapaw are doing within the tribe really has informed how I understand some of the Quapaw words and names that I've come across in old documents. That

has enriched my understanding, and then I can tell readers about how the Quapaw people have seen the world through time.

You describe the history of Native North America as “a combination of victimhood and survival.” Would you say that this is a nuance that is often overlooked in the historical research on Native Americans and, if so, why?

The old story was basically that Native Americans either weren't that important or were savage and obstacles to American progress. Then in the 1960s, there was a new story that corrected that, but it over-emphasized Native American victimhood. Now, that isn't to say that Native Americans haven't been victims to lots of terrible things, but that's not the only story. In both versions, Native Americans don't have much agency or individuality. What I hope this book does is show Native American history in a much fuller sense—even though, yes, terrible things have happened to Native Americans, they also have done all kinds of important things. They have a long, complicated history, not all of which has to do with other kinds of people.

—Molly Glick

ASTRONOMY

A Mars Moon Rises at Dawn

A **NEW PHOTOGRAPH** from the Perseverance rover on Mars shows the smaller of the planet's two moons—named Deimos—glowing in the Martian sky shortly before sunrise. The origin of the moons has been shrouded in mystery since the beginnings of astronomy. Today, scientists are mostly split between the possibility that the moons once were parts of Mars itself or that they are asteroids that were captured by the planet's gravity.

“They have an enigmatic origin,” says Christopher Edwards, a planetary scientist at North Arizona University and an expert in the Martian moons. “They're a curiosity.”



Deimos has only been captured in photographs from the surface of the Red Planet a few times, and seldom at sunrise. The low light and long exposure make the image hazy and dusky. Many of the white specks in the sky are likely noise, according to NASA, though some may be cosmic rays.

The theory that Deimos and its companion moon Phobos are stray asteroids captured by gravity is supported by observations of reflected light, which suggests they may be composed of carbon-rich rocky material, unlike the iron-rich dust and rocks of Mars surface.

On the other hand, some astronomers have speculated that maybe the moons are made of Mars rock that has somehow become darker through an unknown chemical process. The moons' orbits are nearly circular and travel in roughly the same plane, which makes some think they formed out of rings of ejecta created by an ancient impact, perhaps between Mars and a large asteroid.

"The giant impact was my favorite scenario," says planetary scientist Patrick Michel of the Lagrange Laboratory at the University of Côte d'Azur in France, "because it seemed to be the only way to produce two moons in circular orbits." But more recently scientists have found that asteroid capture could also produce such a configuration, he says.

Phobos is roughly potato-shaped and only about 14 miles across, but it is the larger moon. It orbits just a few thousand miles above the Martian surface, much

closer than any other natural satellite. Deimos is less than half its size and orbits the planet more than 14,000 miles away.

Both Michel and Edwards are part of the Martian Moon Exploration mission due to launch next year, which is designed to bring back rock samples from one of the Martian moons in 2031. These samples could help to settle the question of the origin of the moons. Michel is also a member of the Hera mission, which is bound for the asteroid belt but made a gravity "sling-shot" around Mars in March.

The slingshot trajectory brought the Hera probe to within about 621 miles of Deimos and allowed it to image the moon's rarely seen far side; Michel says the data from that flyby is still being processed.

The discovery of the moons of Mars has a curious history. They have been a subject of speculation since 1610, when the pioneering Italian astronomer Galileo Galilei first observed the rings of Saturn through a telescope he'd built himself. Galileo then wrote a cryptic message in letters to announce his discovery—an established scientific practice at the time, to hide his disclosure if it later turned out not to be true. The message was "smaismrmilmepoetaleumibunenugttauiras," by which Galileo meant "I have observed the highest planet tri-form" (because he imagined the two sections of rings he saw on each side of Saturn were part of the planet).

But his message was misinterpreted by the contemporary astronomer Johannes Kepler, then living in the Austrian city of Linz, who announced in subsequent letters that Galileo had seen two moons around Mars. The supposed discovery aligned with Kepler's own speculations, in which he reasoned Mars must have more moons than Earth because Galileo had already seen five moons around Jupiter.

But this supposition wasn't proven true until more than 250 years later, when the American astronomer Asaph Hall first observed the Martian moons in 1877 with a refracting telescope at the U.S. Naval



The discovery of the moons of Mars has a curious history.

Observatory in Washington D.C.—the largest in the world at that time. Hall gave the Martian moons their names, Deimos and Phobos, after Homer’s names for the sons and charioteers of the war god Ares—the Greek equivalent of the Roman god Mars. (Translations vary, but according to NASA, *deimos* means dread, while *phobos* means fear.)

Recent flybys suggest that Deimos is made from slightly different rocky material than Phobos, says Edwards, which seems to support the theory of their origins as captured asteroids. Edwards worked on the

Hope mission to Mars led by the United Arab Emirates space agency, which conducted the flybys of Deimos in 2023. But the difference could still be explained if samples from the Mars Moon Exploration mission show the moons are composed of material similar to rocks from Mars, Edwards says. The mission will image both Martian moons over several years and finally attempt a landing on Phobos to gather rock samples for return to Earth.

Asteroid families have distinctive geochemical compositions, and the rock samples could be expected to determine the origin of Phobos, and by extension Deimos (the chances that both moons have different origins are very slim). The Mars Moon Exploration mission “provides a really unique opportunity to solve a lot of questions about these enigmatic moons,” Edwards says. Michel, too, hopes the moon rocks will offer some answers: “It will be good to have real confirmation at last.”

—Tom Metcalfe

ZOOLOGY

Do Bison Belong in Spain?

FERNANDO MORÁN’S EPIPHANY came in 2006. A female European bison in the Santillana del Mar Zoo in northern Spain, where he was a visitor, pushed her head through the bars of her enclosure and, as he reached out to her, she lifted him clear off the ground. Morán is certain the bison had an urgent message for him: Our species is in trouble.

“I’m really convinced after 15 years working with bison, that she just came to tell me ‘hey, there’s some things to do here, so stop doing what you’re doing and start helping,’” says Morán.

Within two years, the trained veterinarian had transitioned from working in game management and forestry and running a veterinary clinic to devoting himself to *Bison bonasus*. Today, Morán, 54, leads the European Bison Conservation Center in Spain, part of a wider network linking bison breeders to one another in countries where populations of the once critically endangered species are now growing. He is at the

forefront of a large-scale campaign to bring bison back to the Iberian peninsula.

The European bison rewilding project seems at first like an easy, feel-good success story, much like similar efforts in the United States to revive its close cousin the American bison. (That project got underway with the formation in 1905 of the American Bison Society, one of whose founders was Theodore Roosevelt.) Europe’s heaviest land mammal—adult males weigh up to 2,000 pounds—went extinct in the wild in the 1920s but was reintroduced into Poland’s Białowieża Forest in the 1950s. Since then, breeding programs and other reintroduction initiatives have boosted herds on the continent to over 9,000 animals. *B. bonasus* now roams the meadows and shadowy woodlands of many European countries.

Dozens of YouTube videos and articles about the European bison’s comeback hail the revival of these iconic beasts, and the videos have views in the thousands



and hundreds of thousands. Some writings take an almost religious tone: “I believe in the power of nature, which in wild Europe, includes the almighty European bison,” writes one bison conservationist. The creature’s mystique goes back thousands of years: Paleolithic cave paintings of the bison in Europe suggest to some scholars that it had a connection to the spirit world, and the animal has long been sacred to indigenous cultures in the U.S., where it is seen as a symbol of strength and plenty.

People seem to really love bison. But it turns out that not everyone wants them.

Last year, a few dozen scientists from a range of institutions in Spain as well as the U.S., Switzerland, Australia, Germany, Italy, Hungary, and Poland signed a paper in *Conservation Science and Practice* calling for a stop to bison rewilding in Spain. They argue the species is a poor fit for the Iberian peninsula. “The debate [in Spain] between bison ‘yes’ or bison ‘no’ has never taken place at the level of scientific publications; it’s only been at the media level,” said Carlos Nores, a retired zoology professor who taught at the University of Oviedo in northern Spain, and one of the authors of the paper. Morán disagrees, arguing that his critics have refused to engage with more recent data on the bison’s impact, that shows they are doing fine and have had no harmful effects. So far there are 184 bison spread across 12 different properties in Spain.

The crux of the debate in Spain seems to hinge on whether the bison really ever roamed the Iberian peninsula thousands of years ago, and whether a warming climate is hospitable to the animal. During the Late Pleistocene, *Bison bonasus* was widespread in Europe, according to a 2023 research paper in *Proceedings of the Royal Society B*. But there is little hard evidence that in these early years their extensive range included what is now Spain.

The authors of the *Royal Society* paper conclude that Central and Eastern Europe—sites of initial reintroductions—harbor the best habitat for the species. Spain



People seem to really love bison. But it turns out that not everyone wants them.

would seem rather far off the map. But those pushing for bison on the Iberian Peninsula, including Morán, argue that certain beloved cave paintings are a sure sign that thousands of years ago the shaggy beasts once lived here and should return.

The Cave of Altamira in the Cantabrian region of northern Spain contains evocative images of bison painted by stone-age humans 14,000 years ago, which have had a cultural resonance in the country since their discovery in the late 19th century. The government of the region of Cantabria uses these images as tourist logos. (An American football team in Spain also calls itself the Cantabria Bisons.) The consensus view, however, is that the species depicted in this UNESCO World Heritage Site is actually a different bovine that has been extinct not for just a century but for 10,000 years: the steppe bison (*Bison priscus*).

**WATCH YOUR STEPPE**

Cave drawings, like this one in the Cave of Altamira in Spain, suggest that bison were once native to the region.

An even stickier argument concerns the climate, which has changed quite a bit in the thousands of years since the animals depicted at Altamira grazed. During the late Pleistocene the steppe extended into the Iberian peninsula. It was dry, tundra-like, and mostly treeless. But today, Spain is a much hotter place and it's warming faster than much of the rest of the planet.

"The environmental conditions of the Iberian peninsula are not appropriate for this species," Nores says. A high level of mortality and low-level birthrate compared to wild populations in Central and Eastern Europe bears this out, according to Nores, with far more deaths than births in the first 10 years of introducing bison into Spain. But rewilding success stories are often crooked, with many false starts, rather than following a straight line, and Morán counters the deaths were largely due to a lack of sufficient grazing area across which the animals could roam.

He's been giving them more room to spread out, and that is seeming to help, he says. For example, out of the 18 bison introduced at the end of 2020 into Encinarejo—located in the Andalusian municipality of Andújar, 195 miles south of Madrid, which Morán acknowledges is one Spain's "frying pans"—all have survived four summers with five heatwaves, says Morán. He argues that this attests to "the plasticity" of the species.

Aside from helping the species survive extinction, the main ecological argument for bison rewilding is the ecosystem services they provide. As foragers, they gobble up woody plants and open up terrain for other

species, while creating meadows that are more fire-resistant than forest. This is particularly crucial to the vast swathes of Spanish lands that were once home to cattle and other livestock that have been abandoned as the country urbanizes. Organizations like Rewilding Europe tout this ecological services thesis in popular videos championing the benefits of spreading *B. bonasus* throughout the continent. But Nores believes other herbivores such as red deer do an even better job at keeping woody plants from growing too densely, and they're inarguably native to Spain.

The iconic status of the bison is certainly playing a part in its recovery. Rewilding Europe's 2014-2024 Bison Rewilding Plan makes a pitch for ecotourism. But charisma presents its own dangers. Introduced "emblematic species are always hard to get rid of, if they start causing problems," Nores says, citing the case of the cocaine hippos in Colombia. Descendants of the drug lord Pablo Escobar's captive herd, these hippos now number 200 and roam freely throughout the countryside. They're dangerous animals, could crowd out native endangered species, and have already increased nutrient loads in waterways, which could lead to oxygen-sucking algae blooms. And due to outcry from animal rights activists over government plans to euthanize them, Colombia is pursuing a costly program of sterilization instead.

So far no one expects bison populations to explode in such a manner. In fact, at Encinarejo, the owners are so pleased with the bison that they're working on bringing another endangered species into Spain: Przewalski's horse.

As for Morán, he has no plans to turn his back on the bison.

—Felipe Ossa

GEOSCIENCE

Mapping the Earth's Magnetism

A **S LEGEND HAS IT**, a shepherd named Magnes first discovered magnetism. While traversing Mount Ida in what is now northwestern Turkey around 1000 B.C., he noticed that the metal cap of his staff and the nails in his shoes were ineluctably drawn to certain rocks. He dug to uncover the origin of this powerful attraction and discovered the mineral magnetite, a magnetic oxide of iron, suffusing a chunk of lodestone.

Many centuries later, people in China invented the first magnetic compass, most likely some time before 100 A.D. But at first, this powerful new technology was primarily used as a divining tool by feng shui practitioners. It was not until the 1200s that magnetic compasses came into regular use for wayfaring, helping intrepid Chinese and European travelers to cross land and sea.

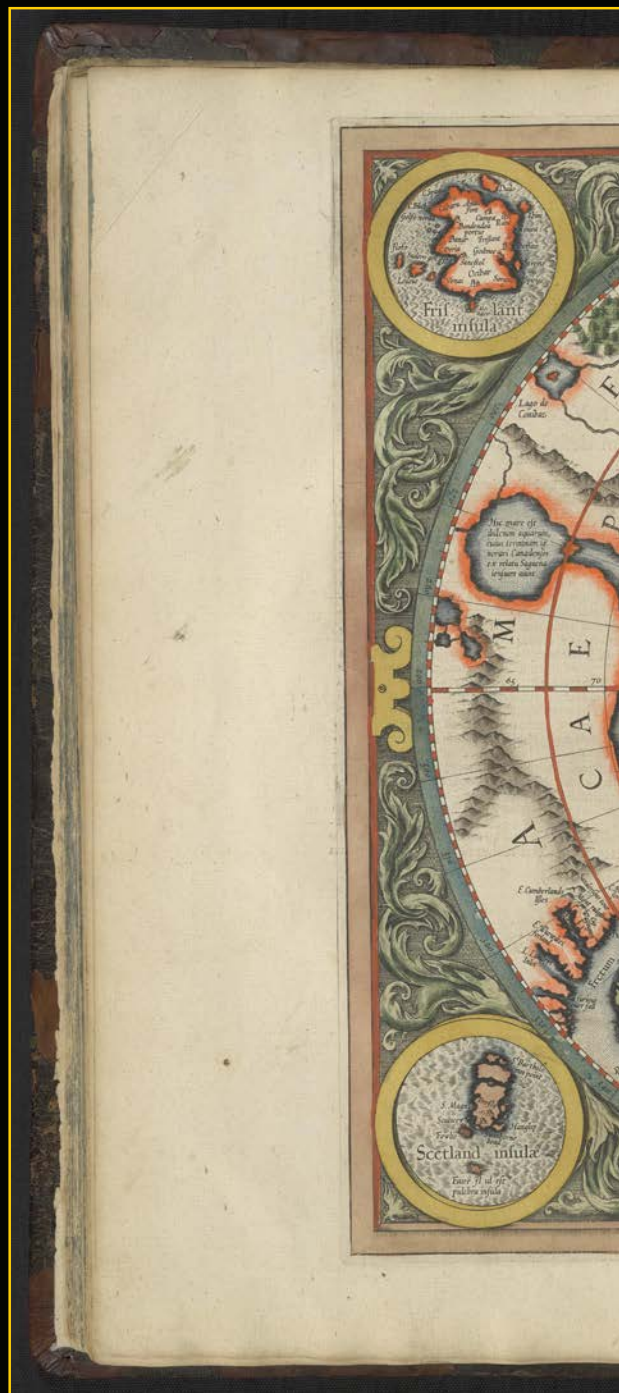
By that time, many scholars understood that the compass needle did not point toward true north, the axis of rotation of the Earth, but rather to the magnetic north pole, which is distinct. The angular difference between true north and magnetic north is called magnetic declination, and its discovery in China and Europe led to a flurry of map making and scientific exploration aimed at explaining both the nature and the source of the Earth's magnetic pull.

Many early scientists speculated that the north star or certain mountains and rocks must be responsible for the magnetism on Earth. In the first published map of the Arctic and the North Pole, from 1569, Flemish cartographer Gerhard Mercator depicted alluring cliffs and rocks thought to contribute to the polar magnetic field. An enlarged second edition (right) shows at its center an inky gnarled island labeled "*Rupus Nigra et Altissima*," which translates to "very high black cliff," and which he described in a letter to English mathematician John Dee as consisting "all of magnetic stone," and measuring 33 miles across.

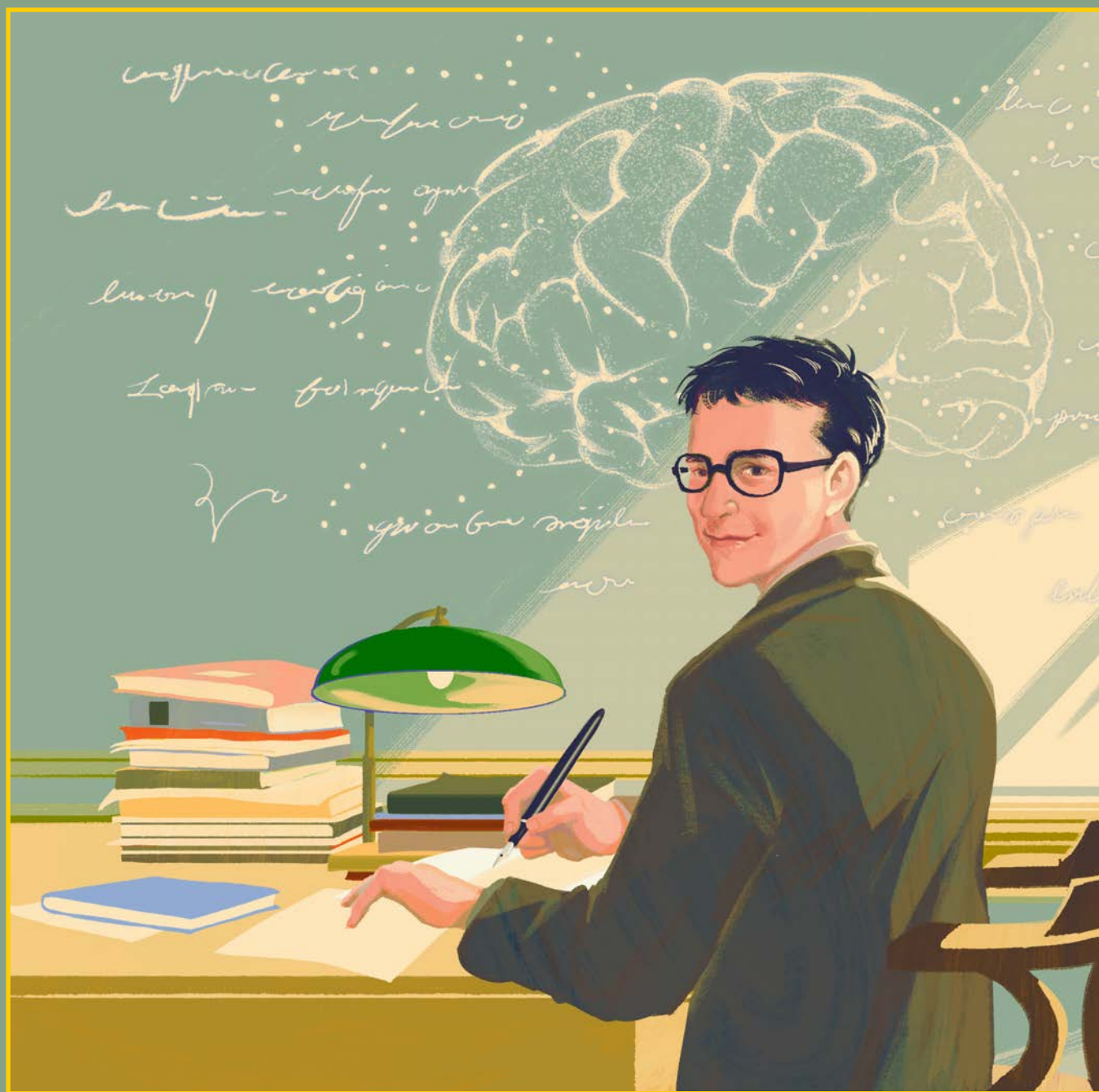
Today we understand that the Earth's magnetic field is generated by the flux of molten iron in its core, which creates an electrical current that flows around the equator in an imperfect loop. But much about how this field works and shifts over time remains a mystery to be divined and mapped by future explorers.

—Kristen French

Photos courtesy of the Library of Congress, Rare Book and Special Collections Division







The forgotten janitor who discovered the logic of the mind

THE NEIGHBORHOOD WAS QUIET. There was a chill in the air. The scent of Spanish moss hung from the cypress trees. Plumes of white smoke rose from the burning cane fields and stretched across the skies of Terrebonne Parish. The man swung a long leg over a bicycle frame and pedaled off down the street.

A screech shot down the corridor of East Main Street, echoed through the vacant lots, and rang out over the Bayou. Then silence.

ILLUSTRATION BY CORNELIA LI

How could this genius just vanish into obscurity?

His name was Peter Putnam. He was a physicist who'd hung out with Albert Einstein, John Archibald Wheeler, and Niels Bohr, and two blocks from the crash, in his run-down apartment, where his partner, Claude, was startled by a screech, were thousands of typed pages containing a ground-breaking new theory of the mind.

"Only two or three times in my life have I met thinkers with insights so far reaching, a breadth of vision so great, and a mind so keen as Putnam's," Wheeler said in 1991. And Wheeler, who coined the terms "black hole" and "wormhole," had worked alongside some of the greatest minds in science.

Robert Works Fuller, a physicist and former president of Oberlin College, who worked closely with Putnam in the 1960s, told me in 2012, "Putnam really should be regarded as one of the great philosophers of the 20th century. Yet he's completely unknown."

That word—*unknown*—it came to haunt me as I spent the next 12 years trying to find out why.

THE AMERICAN PHILOSOPHICAL SOCIETY LIBRARY in Philadelphia, with its marbled floors and chandeliered ceilings, is home to millions of rare books and manuscripts, including John Wheeler's notebooks. I was there in 2012, fresh off writing a physics book that had left me with nagging questions about the strange relationship between observer and observed. Physics seemed to suggest that observers play some role in the nature of reality, yet who or what an observer is remained a stubborn mystery.

Wheeler, who made key contributions to nuclear physics, general relativity, and quantum gravity, had thought more about the observer's role in the universe than anyone—if there was a clue to that mystery anywhere, I was convinced it was somewhere in his papers. That's when I turned over a mylar overhead, the kind people used to lay on projectors, with the titles of two talks, as if given back-to-back at the same unnamed event:

Wheeler: From Reality to Consciousness

Putnam: From Consciousness to Reality

THE SCHOLAR

Peter Putnam catches up with the news while studying at the University of Leiden in 1956.

Putnam spent a semester in the Netherlands working as an assistant to physicist John Archibald Wheeler.

JOHN ARCHIBALD WHEELER, COURTESY OF ALISON LAHNSTON





Putnam, it seemed, had been one of Wheeler's students, whose opinion Wheeler held in exceptionally high regard. That was odd, because Wheeler's students were known for becoming physics superstars, earning fame, prestige, and Nobel Prizes: Richard Feynman, Hugh Everett, and Kip Thorne.

Back home, a Google search yielded images of a very muscly, very orange man wearing a very small speedo. This, it turned out, was the wrong Peter Putnam. Eventually, I stumbled on a 1991 article in the *Princeton Alumni Weekly* newsletter called "Brilliant Enigma." "Except for the barest outline," the article read, "Putnam's life is 'veiled,' in the words of Putnam's lifelong friend and mentor, John Archibald Wheeler."

A quick search of old newspaper archives turned up an intriguing article from the *Associated Press*, published six years after Putnam's death. "Peter Putnam lived in a remote bayou town in Louisiana, worked as a night

watchman on a swing bridge [and] wrote philosophical essays," the article said. "He also tripled the family fortune to about \$40 million by investing successfully in risky stock ventures."

The questions kept piling up. *Forty million dollars?*

I searched a while longer for any more information but came up empty-handed. But I couldn't forget about Peter Putnam. His name played like a song stuck in my head. I decided to track down anyone who might have known him.

The only paper Putnam ever published was co-authored with Robert Fuller, so I flew from my home in Cambridge, Massachusetts, to Berkeley, California, to meet him. Fuller was nearing 80 years old but had an imposing presence and a booming voice. He sat across from me in his sun-drenched living room, seeming thrilled to talk about Putnam yet plagued by some palpable regret.

“We got the sense that what Einstein’s general theory was for physics, Peter’s model would be for the mind.”

Putnam had developed a theory of the brain that “ranged over the whole of philosophy, from ethics to methodology to mathematical foundations to metaphysics,” Fuller told me. He compared Putnam’s work to Alan Turing’s and Kurt Gödel’s. “Turing, Gödel, and Putnam—they’re three peas in a pod,” Fuller said. “But one of them isn’t recognized.”

Fuller led me to Barry Spinello, a filmmaker in Bakersfield, California, who met Putnam at the Apollo Theater in Harlem in 1963. Cannonball Adderley was wailing on the sax. “I turned around and saw this guy doing a ridiculous dance,” Spinello said—half jive, half seizure. Putnam was tall and thin like an overgrown twig, flailing like he might tie himself into a knot. They got to talking, and Spinello found Putnam so fascinating that, 10 years later, he traveled to Louisiana to record a week’s worth of conversations about his work.

For nights on end, on a cot in Spinello’s studio, I slept to the clicks and hums of an achy reel-to-reel machine, as it fed 35 hours of audio into my digital recorder. I listened to one of the recordings in my headphones on the plane ride back, flinching when Putnam’s voice broke through the static. Suddenly he became a real person, a person with vocal cords. He sounded like Jimmy Stewart with a stutter. “Sometimes I think it would’ve worked with Wheeler,” he was saying, “but it just ...” Then he went silent.

Spinello gave me an email address for Coleman Clarke, who had met Putnam in New York City in the 1960s while Clarke was doing his Ph.D. at Columbia University. “It’s mind blowing to me that you found Putnam in Wheeler’s journals,” Clarke wrote in reply, as if I’d won a scavenger hunt that everyone else had quit playing decades ago.

Clarke seemed relieved that someone had finally come around asking about Putnam, eager to tell me about this extraordinary man who had slipped through the cracks of history. “He was a genius,” Clarke said. “Every talk with him had this level of significance that was just orders of magnitude higher up than a normal conversation with a normal human being.”

One person led to another. Gary Aston-Jones, head of the Brain Health Institute at Rutgers University, told me he was inspired by Putnam to go into neuroscience after Clarke gave him one of Putnam’s papers.

“Putnam’s nervous system model presaged by decades stuff that’s very cutting edge in neuroscience,” Aston-Jones said, and yet, “in the field of neuroscience, I don’t know anybody that’s ever heard of him.”

Phillips Jones, a physicist who worked alongside Putnam in the early 1960s, told me over the phone, “We got the sense that what Einstein’s general theory was for physics, Peter’s model would be for the mind.”

Even Einstein himself was impressed with Putnam. At 19 years old, Putnam went to Einstein’s house to

Putnam's remarkable claim was that simply by playing this game, the system will learn.

talk with him about Arthur Stanley Eddington, the British astrophysicist. (Eddington performed the key experiment that proved Einstein's theory of gravity.) Putnam was obsessed with an allegory by Eddington about a fisherman and wanted to ask Einstein about it. Putnam also wanted Einstein to give a speech promoting world government to a political group he'd organized. Einstein—who was asked by plenty of people to do plenty of things—thought highly enough of Putnam to agree.

How could this genius, this Einstein of the mind, just vanish into obscurity? When I asked why, if Putnam was so important, no one has ever heard of him, everyone gave me the same answer: because he didn't publish his work, and even if he had, no one would have understood it.

"He spoke and wrote in 'Putnamese,'" Fuller said. "If you can find his papers, I think you'll immediately see what I mean."

IN A JANUARY FREEZE in 2013, I headed to Rochester, New York, to meet Clarke. He was in his late 70s but looked younger—tall and slim with gray hair and a bounce in his step. "I'm just so excited that you've found Putnam," he said warmly. It sounded like, *what took you so long?* He told me he had some of Putnam's papers in storage.

We drove to a nondescript brick building. I followed him down a cold, white hallway until he stopped in front of one of the units. He turned the key and lifted the massive door.

You have to understand what I was expecting. I thought we were going to his storage unit, that it would be filled with whatever storage units are filled with—old clothes and rusty bikes, mismatched chairs and unused exercise equipment. Then somewhere, beneath a pile of something, in a dusty cardboard box, a few of Putnam's papers.

PARTNERS John "Claude" DeBrew and Peter Putnam in Houma, Louisiana, circa 1978. Putnam met DeBrew, an ex-Army major, in a Harlem jazz club. They lived together for 17 years before Putnam died.

COURTESY OF COLEMAN CLARKE



That's not what this was.

As the door rolled up, I caught a glimpse of what lay behind.

"This is all Putnam?" I whispered.

Clarke nodded. "I've never shown anyone before you."

There were no old clothes. No mismatched chairs. Only filing cabinets. Rows of filing cabinets, all neatly labeled, giving the whole place the appearance of a professional archive. I looked around, stunned. It was the entire library of Putnam's unpublished writings. His theory, his life. The whole long-lost thing.

When Clarke first heard that Putnam had been killed, he made frantic phone calls to the Putnam family lawyer to find out what was happening with Peter's papers. The answer seemed to be nothing—they'd been moved from Houma to a Cleveland warehouse and might have been thrown away. Clarke rushed to Ohio, loaded them onto a truck, and drove them to his home in Utah for safe keeping; when he moved to Rochester, the archive moved with him.

Now he dug through drawers, handing me papers and folders until I was holding a stack so large I nearly toppled over. Typed manuscripts at hundreds of pages apiece; binders full of notes and letters; handwritten journals; accordion folders bursting with photos, telegrams, and postcards—we piled as much as we could into the trunk of my rental car and I drove back to my hotel.

It's one thing to read through curated papers at a place like the American Philosophical Society, with pages gingerly propped on foam wedges under the watchful eyes of librarians. It's another to flop down on a white bedspread in a Courtyard Marriott and hold a man's unprocessed life, alone. You turn it over in your hands, still covered in his pencil marks, smudged with his fingerprints; an envelope singed in the spiral shape of his stove ring, yellowed glue clutching his pet bird's tattered feather, a letter torn apart seemingly in anger and taped back together in remorse. Suddenly you're implicated. You've disturbed a sleeping thing.

Skimming through the papers I saw that the people I'd spoken to hadn't been kidding about the Putnam-ese. "To bring the felt under mathematical categories involves building a type of mathematical framework within which latent colliding heuristics can be exhibited

as of a common goal function," I read, before dropping the paper with a sigh. Each one went on like that for hundreds of pages at a time, on none of which did he apparently bother to stop and explain what the whole thing was really about.

There was no way I could read it all in a reasonable amount of time, so I spent the next week driving between my hotel and the storage unit. I'd stay up all night, photographing the items page by page, then head back to the storage unit, bleary-eyed in the daylight, to swap it all out for a new batch. I'd already photographed some 10,000 pages of material when Clarke grinned and confessed, "There's a second storage unit."

Back in my apartment in Cambridge, I began sorting through everything I'd found. Photographs, letters, transcripts, papers—I spread them on the kitchen table like pieces to a jigsaw puzzle. Gradually, Putnam's life and the scope of his theory came into view.

He developed it over the course of three decades, starting as a teenager in the 1940s. He wrote constantly—in the Navy, when he was sent to the brig for reading poetry on duty; while earning his degrees at Princeton University, and after, teaching physics at the University of Massachusetts at Amherst in the 1950s and Columbia University in New York in the 1960s. He wrote while he was living in Fuller's office at Barnard College with little more than a cot, a phonograph, and a hot plate, and when he moved into a basement apartment in upper Manhattan, just west of Harlem, his lanky form hunched over a typewriter between the grated window bars.

Putnam spent most of his time alone, Fuller had told me. "Because of this isolation, he developed a way of expressing himself in which he uses words, phrases, concepts, in weird ways, peculiar to himself. The thing would be totally incomprehensible to anyone."

I took the incomprehensibility as a test. I didn't know why I was being tested. I only knew I wanted to pass. I was driven in part by the looks on everyone's faces, a pain that appeared fresh despite the years. "My basic upset is, I feel somehow I failed to get his stuff out there," Fuller said. Wheeler had felt the same. "I realize I didn't do my duty by Peter," he said after Putnam died.

Their regret was now my inheritance, a whisper that grew louder as the years pressed on. I might have

Whenever Putnam made a new friend, his mother warned him, “They’re probably using you for your money.”

walked away if I hadn’t been struck with the same feeling that had taken hold of everyone else: that Putnam was actually onto something. That he was quite possibly a genius. In the beginning, I was chasing Peter Putnam the fantasy, a forgotten janitor who’d discovered the structure of the mind. But the deeper I read, I found myself thinking, *Wait, did a forgotten janitor seriously discover the structure of the mind?*

IMAGINE A FISHERMAN who’s exploring the life of the ocean. He casts his net into the water, scoops up a bunch of fish, inspects his catch and shouts, “A-ha! I have made two great scientific discoveries. First, there are no fish smaller than two inches. Second, all fish have gills.”

The fisherman’s first “discovery” is clearly an error. It’s not that there are no fish smaller than two inches, it’s that the holes in his net are two inches in diameter. But the second discovery seems to be genuine—a fact about the fish, not the net.

This was the Eddington allegory that obsessed Putnam.

When physicists study the world, how can they tell which of their findings are features of the world and which are features of their net? How do we, as observers, disentangle the subjective aspects of our minds from the objective facts of the universe? Eddington suspected that one couldn’t know anything about the fish until one knew the structure of the net.

That’s what Putnam set out to do: come up with a description of the net, a model of “the structure of thought,” as he put it in a 1948 diary entry.

At the time, scientists were abuzz with a new way of thinking about thinking. Alan Turing had worked out an abstract model of computation, which quickly led not only to the invention of physical computers but also to the idea that perhaps the brain, too, was a kind of Turing machine.

Putnam disagreed. “Man is a species of computer of fundamentally different genus than those she builds,” he wrote. It was a radical claim (not only for the mixed genders): He wasn’t saying that the mind isn’t a computer, he was saying it was an entirely *different* kind of computer.

A universal Turing machine is a powerful thing, capable of computing anything that can be computed by an algorithm. But Putnam saw that it had its limitations. A Turing machine, by design, performs deductive logic—logic where the answers to a problem are contained in its premises, where the rules of inference are pregiven, and information is never created, only shuffled around. Induction, on the other hand, is the process by which we come up with the premises and rules in the first place. “Could there be some indirect way to model or orient the induction process, as we do deductions?” Putnam asked.

Putnam laid out the dynamics of what he called a universal “general purpose heuristic”—which we might call an “induction machine,” or more to the point, a





mind—borrowing from the mathematics of game theory, which was thick in the air at Princeton. His induction “game” was simple enough. He imagined a system (immersed in an environment) that could make one mutually exclusive “move” at a time. The system is composed of a massive number of units, each of which can switch between one of two states. They all act in parallel, switching, say, “on” and “off” in response to one another. Putnam imagined that these binary units could condition one another’s behavior, so if one caused another to turn on (or off) in the past, it would become more likely to do so in the future. To play the game, the rule is this: The first chain of binary units, linked together by conditioned reflexes, to form a self-reinforcing loop emits a move on behalf of the system.

Every game needs a goal. In a Turing machine, goals are imposed from the outside. For true induction, the process itself should create its own goals. And there was a key constraint: Putnam realized that the dynamics he had in mind would only work mathematically if the system had just *one* goal governing all its behavior.

That’s when it hit him: The goal is to repeat. Repetition isn’t a goal that has to be programmed in from the outside; it’s baked into the very nature of things—to exist from one moment to the next is to repeat your existence. “This goal function,” Putnam wrote, “appears pre-encoded in the nature of being itself.”

So, here’s the game. The system starts out in a random mix of “on” and “off” states. Its goal is to repeat that state—to stay the same. But in each turn, a perturbation from the environment moves through the system, flipping states, and the system has to emit the right sequence of moves (by forming the right self-reinforcing loops) to alter the environment in such a way that it will perturb the system back to its original state.

Putnam’s remarkable claim was that simply by playing this game, the system will learn; its sequences of moves will become increasingly less random. It will create rules for how to behave in a given situation, then automatically root out logical contradictions among those rules, resolving them into better ones. And here’s the weird thing: It’s a game that can never be won. The system never exactly repeats. But in trying to, it does something better. It adapts. It innovates. It performs induction.

HAPPY DAYS Peter Putnam in his Navy uniform shares a laugh with his mother, Mildred Andrews Putnam, at their home on Lake Shore Boulevard in the affluent village of Bratenahl, Ohio, circa 1944.

“Perhaps I have actually found a place in the world that wants me at last—as I am.”

In paper after paper, Putnam attempted to show how his induction game plays out in the human brain, with motor behaviors serving as the mutually exclusive “moves” and neurons as the parallel binary units that link up into loops to move the body. The point wasn’t to give a realistic picture of how a messy, anatomical brain works any more than an abstract Turing machine describes the workings of an iMac. It was not a biochemical description, but a logical one—a “brain calculus,” Putnam called it.

As the game is played, perturbations from outside—photons hitting the retina, hunger signals rising from the gut—require the brain to emit the right sequence of movements to return to its prior state. At first it has no idea what to do—each disturbance is a neural impulse moving through the brain in search of a pathway out, and it will take the first loop it can find. That’s why a newborn’s movements start out as random thrashes. But when those movements don’t satisfy the goal, the disturbance builds and spreads through the brain, feeling for new pathways, trying loop after loop, thrash after thrash, until it hits on one that does the trick.

When a successful move, discovered by sheer accident, quiets a perturbation, it gets wired into the brain as a behavioral rule. Once formed, applying the rule is a matter of deduction: The brain outputs the right move without having to try all the wrong ones first.

But the real magic happens when a contradiction arises, when two previously successful rules, called up in parallel, compete to move the body in mutually exclusive ways. A hungry baby, needing to find its mother’s breast, simultaneously fires up two loops,

conditioned in from its history: “when hungry, turn to the left” and “when hungry, turn to the right.” Deductive logic grinds to a halt; the facilitation of either loop, neurally speaking, inhibits the other. Their horns lock. The neural activity has no viable pathway out. The brain can’t follow through with a wired-in plan—it has to create a new one.

How? By bringing in new variables that reshape the original loops into a new pathway, one that doesn’t negate either of the original rules, but clarifies which to use when. As the baby grows hungrier, activity spreads through the brain, searching its history for anything that can break the tie. If it can’t find it in the brain, it will automatically search the environment, thrash by thrash. The mathematics of game theory, Putnam said, guarantee that, since the original rules were in service of one and the same goal, an answer, logically speaking, can always be found.

In this case, the baby’s brain finds a key variable: When “turn left” worked, the neural signal created by the warmth of the mother’s breast against the baby’s left cheek got wired in with the behavior. When “turn right” worked, the right cheek was warm. That extra bit of sensory signal is enough to tip the scales. The brain has forged a new loop, a more general rule: “When hungry, turn in the direction of the warmer cheek.”

New universals lead to new motor sequences, which allow new interactions with the world, which dredge up new contradictions, which force new resolutions, and so on up the ladder of ever-more intelligent behavior. “This constitutes a theory of the induction process,” Putnam wrote.

In notebooks, in secret, using language only he would understand, Putnam mapped out the dynamics of a system that could perceive, learn, think, and create ideas through induction—a computer that could program itself, then find contradictions among its programs and wrangle them into better programs, building itself out of its history of interactions with the world. Just as Turing had worked out an abstract, universal model of the very possibility of computation, Putnam worked out an abstract, universal model of the very possibility of mind. It was a model, he wrote, that “presents a basic overall pattern [or] character of thought in causal terms for the first time.”

PUTNAM HAD SAID you can’t understand another person until you know what fight they’re in, what contradiction they’re working through. I saw before me two stories, equally true: Putnam was a genius who worked out a new logic of the mind. And Putnam was a janitor who died unknown. The only way to resolve a contradiction, he said, is to find the auxiliary variables that forge a pathway to a larger story, one that includes and clarifies both truths. The variables for this contradiction? Putnam’s mother and money.

Putnam grew up with money. He was born in 1927 in Ohio, to John B. Putnam, Sr., charming corporate lawyer, and Mildred Andrews Putnam, fearsome lady-who-lunched. They lived in the village of Bratenahl, a tiny neighborhood outside Cleveland, home to the ultrarich, in a big, white Victorian house with a round cone-topped turret and the expanse of Lake Erie unfurling from their backyard. Whenever Putnam made a new friend, his mother warned him, “They’re probably using you for your money.”

When Putnam and his older brother, Johnny, were little, their parents told them a story about a boy named Ikey. Ikey’s father had lifted Ikey up and sat him high up on the mantle above the fireplace. Then the father told him, “OK, Ikey. Jump!”

“He is afraid,” Putnam wrote, “but told his daddy will catch him. He is afraid, but told to have faith, and all will go well.” So Ikey jumps. But his father doesn’t catch him. He steps to the side, lets the kid fall. “When Ikey cries and complains,” Putnam wrote, “he is told never to trust anyone, not even his mother and father.”

That was the moral of the story that Mildred and John Putnam told to their children. Never trust anyone. Not even us. Johnny cried, but Peter just soaked it in.

At 16, Putnam joined the Navy, and it was there, in radar school, that he realized his aptitude for physics. At the same time, he realized his desperation to unravel the mystery of minds. He needed to understand the secret motives his mother warned about, especially now that he was coming to grips with his homosexuality, which left him feeling helplessly set apart.

In 1944, Putnam received word that his brother, a fighter pilot in the Air Force, had been killed overseas. Peter’s diary entry that day read: “Tuesday—Johnny isn’t.” Johnny had been the Putnam’s golden boy: blond-haired, blue-eyed, confident, athletic. Now there was just Peter: bookish, skinny, painfully shy. The taller of the two, he cultivated a slouch, as if embarrassed by his continued existence. Two years later, still reeling from Johnny’s death, he used his Navy credits to enroll as a physics major at Princeton.

Wheeler took him under his wing, bringing him to Copenhagen to meet Niels Bohr, raving to Bohr about Putnam’s “very great interest in the philosophical aspects of physics.”

After graduation from Princeton, Putnam reluctantly enrolled in Yale Law School. Now that he was the only son, he was expected to become a lawyer like his father and grandfather. Two years later, his father was diagnosed with late-stage leukemia. As he was dying, he told Peter to forget law and use his inheritance to return to his real work. So Peter joined the philosophy department at Harvard University, planning to do a Ph.D. on Eddington. But when his father died in 1951, Mildred, wanting to retain control over the only family she had left, withheld the money. Peter’s decisions would go through her. Peter, determined to make his own money, dropped out of school and took a job at Sanders and Associates, an electronics company in New Hampshire.

From his salary alone, he saved up enough money to quit and return to Princeton to study with Wheeler for his Ph.D. He promptly informed Mildred that he would not accept another dime from her, ever. “I shall not need, and will not accept, any more money from you from here on,” he wrote in a letter.



Cut off from the family money, real friendships suddenly seemed possible. “What a funny delightful sensation it is to be asking for the cheapest rooms, and trying to save money,” he wrote in his diary in 1957. “It makes me smile and smile—as though I had a secret. I can feel the friends I have getting wind of it, and speculating—and the nicest part—is that it makes me feel one of them.” He signed the entry, “Self-righteous Peter.”

One of those friends was Fuller. They were walking across campus when Fuller casually asked what Putnam was working on. Putnam turned to him and asked, “Do you really want to know?”

He’d never told anyone about his theory, but with money no longer blocking the way, it all came spilling out. “We talked and talked till I was bleary-eyed and dead tired and had to quit,” Fuller said.

Putnam dressed in shabby clothes. He sold the Cadillac convertible Mildred had bought him, used the money to buy a bicycle, and gave the remainder of the proceeds to Princeton. He also gave them all the stock he’d earned at Sanders—some 600 shares, valued around \$9,000, which he’d asked for in lieu of raises—on the condition that they wouldn’t sell them until he gave the green light. He did, a decade later, and they sold for more than \$1 million.

Putnam asked that the donations be used to buy great works of modern sculpture to be displayed around campus. Clarke told me Putnam’s love of abstract sculpture came from “his thinking about the brain and the centrality of motor pathways”—the sculptural form resolving an artist’s own contradictions, then inviting the viewer to move, to *think*, in new ways. The collection was to be a memorial to his brother. The donor was to be listed as “Anonymous.”

After a stint teaching physics in Amherst, Putnam followed Fuller to New York City in 1963. Fuller was teaching at Columbia, so Putnam taught a summer seminar in the physics department. His lectures were so heavily laced with philosophy that students from the Union Theological Seminary across the street began showing up. After class they’d go to a nearby café, quoting lines of Putnamese. “Jazz is the mathematization of the soul.” “We know things in the act, not in their essence.” The Seminary hired Putnam, and set him up in the basement apartment on Claremont Ave.

In the day, Putnam taught and wrote; at night he’d walk uptown to Harlem to dance at the jazz clubs, a neural free-for-all to enact his improvisational mind. Most of the time, he was the only white guy there. One night he met a Black ex-Army Major named John DeBrew, who went by the nickname Claude. “Claude sneaked under my defenses as a bird or flower does,” Putnam wrote. “I’ve been most lucky in finding a gentle, affectionate person.” He was open about the relationship with everyone, noting in a letter to Fuller that, when it came to his sexuality, “We should be able to discuss anything, and treat it as we should a problem in mathematics.”

One of Putnam’s students, Kim Hopper, now a medical anthropologist at Columbia, told me that Putnam wrote an article for the *Union Seminary Quarterly Review*, where he mentioned, in an offhanded way, the “depth and sensitivity of the homosexual community, in which I have been privileged

TWO FRIENDS

Oval with Points by sculptor Henry Moore, donated by Peter Putnam, on the Princeton University campus. Putnam’s mentor and champion, John Archibald Wheeler, described the work as a “place for two friends to sit side by side.”

He built walls around his work, walls made of words, but he built them too high—they kept everyone out.

to participate.” “This was at a time when nobody came out,” Hopper said, “especially not in a theological journal!”

“Perhaps I have actually found a place in the world that wants me at last—as I am,” Putnam wrote to his mother. “In any case I am very pleased.”

Mildred was less pleased. She offered Claude \$35,000 to leave Peter. Claude didn’t take the bribe, a move that endeared him to Peter for the rest of their lives. Still, Mildred sent a note to Peter, scribbling: “Remember Ikey.”

BACK IN PRINCETON, Wheeler was coming around to the idea that the observer might be implicated in quantum mechanics, and he knew his best bet for understanding the observer was Putnam. He was hoping that Putnam would return to Princeton so they could work together, uniting a theory of the observer with a theory of the observed. Putnam wanted nothing more. “So many people dream of convincing father images of the value of their work,” he replied.

When Mildred realized what was happening, she jumped in, trying to ensure that Peter would get the job and that he’d owe it all to her. She began dangling donations, offering to build a new physics building at Princeton with Wheeler’s name on it. Wheeler wanted no part of it, but Mildred was a force of nature, a hurricane in pearls. “Hopefully something constructive could be arranged over luncheon,” she wrote to

Wheeler, adding that she wanted to keep the arrangement between themselves. “Will you please forget I ever wrote this letter and throw it into the fire, as Peter would never forgive me.”

Putnam pleaded with her to stay out of his relationship with Wheeler, but she continued to allude to secret meetings and quid pro quo donations until he didn’t know who or what to believe.

Unable to trust that Wheeler’s interest was pure, Putnam refused to consider a position at Princeton, or a fellowship at the nearby Institute for Advanced Study. He stuck with teaching at the Seminary.

It’s clear from Wheeler’s journals his interest in Putnam’s work was genuine and deep. Over and over, he read the few papers that Putnam gave him, writing out notes and questions line by line. “He would throw up his hands in despair,” Wheeler’s daughter, Alison Lahnston, told me, “but he kept at it.”

One morning in 1974, over breakfast in Manhattan, Wheeler took 12 pages of notes as Putnam talked about his work, then submitted a book proposal to W.H. Freeman & Company on Putnam’s behalf. The publishers bit, and were ready to draw up a contract, but Putnam again worried that his mother was behind the offer, and refused to sign.

Just then, a perfect opportunity arose to present Putnam to the public. Wheeler was invited by the Neurosciences Research Program at MIT to speak at their March 1975 meeting on “reality and consciousness.”

He insisted he could only do it as half of a pair. *From Reality to Consciousness. From Consciousness to Reality.*

As the meeting approached, Putnam grew nervous. He demanded to know whether Mildred had been involved behind the scenes. Wheeler assured him that she wasn't, that the talks were solely his idea. Together, they boarded a plane to Boston.

I listened to the meeting, recorded on a reel-to-reel, stowed away in the archives at MIT. Here, finally, was Putnam's chance to explain his ideas to the top neuroscientists of the time. I pressed the headphones tight against my ears.

Wheeler had just finished speaking about the observer in quantum mechanics and introduced Putnam with a warning. "Some terms Peter uses, one needs a glossary to translate." Wheeler placed a transparency on the projector—he'd made an actual glossary of Putnam's terms. The crowd burst into laughter. I didn't have to see Putnam's face to feel it growing hot. When he began to speak, he stuttered.

"You only perceive signals that are useful for shaping behavior ... A game is a special kind of mathematics ... But for a game you need a goal function ... We're suggesting that the category repetition is a candidate ... You're searching for rules of choice that allow a repeating or self-reproducing path ... There's a transcendental core to the laws of physics themselves ..."

The crowd grew restless. Wheeler's talk had gone long, and there wasn't time for Putnam to finish. The neuroscientists headed out for lunch and the tape cut out.

Things went from bad to worse. Back in New York, Putnam learned he'd lost his job at Union. The President cited "budgetary concerns," which Putnam took as a veiled attempt to ask for a donation, suspecting that his mother had suggested as much to the administration behind his back.

Wheeler made one last ditch effort to convince Putnam not to give up on academia. I found a handwritten note he wrote in 1975. Not a note, exactly—more like an affidavit.

"I find it utterly impossible to believe that your mother directly or indirectly made any contributions to, or in any way influenced, the action of the Institute for Advanced Study, MIT Neurophysiology, [or] Freeman and Company ... I have never been and do

not intend to be a party to any arrangement in which relations between you and me, or between you and any institutional setting in which I have any say or knowledge, are dependent in any way whatsoever on any contribution, or any expectation of any contribution, from your mother. There is no lawyer-like or other reservations or loophole in the intent and content of this freely given assurance."

But even Wheeler couldn't penetrate Putnam's defenses. *Never trust anyone.* It was a rule of behavior that had dug a trench in his neural circuitry, formed a universal, self-reinforcing loop, and no matter how many alternatives competed with it in parallel, it was always strengthened. It always won. He couldn't risk having people take a cursory interest in his work just to flatter him, to court him for his money. To weed out anyone who wasn't in it for the right reasons, he refused to provide an easy summary. It was total commitment or nothing at all. So he built walls around his work, walls made of words, but he built them too high—they kept everyone out, and kept Putnam in.

In June 1975, Putnam sat down and wrote a letter to Wheeler:

"It should be obvious that what I'm doing is a lot of nonsense. I didn't convince any of the big boys at the conference—didn't even get any excited about any of the points or themes ... Clearly all I've been doing is hoodwinking a few naive though often top students—after ten years of teaching my crazy course ... finally, the right thing has been done."

Putnam placed his books on a table at Union Seminary for the taking, dumped stacks of manuscripts in the trash, gave his records and turntable to a janitor. Then he opened to a fresh page in his journal and scrawled, "For myself, given my weaknesses, this is the end. I can't try any more ... At least I've finished things off. It fits well enough—for a start for someone else ... The best I can do—like Rimbaud—is to vanish."

AN OIL TOWN built on the swamplands between the Mississippi River and the Gulf of Mexico, Houma, Louisiana, is about an hour's drive southwest from New Orleans. In 1975, Putnam had signed himself and Claude up for VISTA—Volunteers in Service of America, the domestic branch of the Peace Corps—and VISTA sent them to Houma. They were promised

government housing, but when the building manager saw that Claude was Black, their apartment suddenly became unavailable. They tried another housing project. Same story. Finally, they went to Senator Circle, the Black project on the other side of town, but they weren't welcome there either. Interracial *and* gay—there was no housing project for that. So Putnam found them a spot in a trailer park. The landlady said she'd pray for them.

They reported for VISTA duties at the Wayout Clinic, a nonprofit serving the Black community in Terrebonne Parish. The city had scraped together funds to open a new rec center and they'd asked Wayout to run it. Putnam asked the program director why they couldn't just give the money directly to the Black community and let them run their own rec center instead of having a bunch of white people in charge. The director told Putnam that it was impossible, that there were legal complexities he wouldn't understand; it would have to go through a nonprofit, it was very complicated. Putnam didn't mention that he was a physicist or that he'd studied at Yale Law. He just turned around and registered a new nonprofit, the Terrebonne Improvement Association (TIA). He put together an all-Black Board of Directors, then applied for VISTA volunteers of their own.

The TIA published their own community newsletter, featuring pieces by local Black writers alongside transcripts of speeches by national civil rights leaders. Claude delivered speeches to the TIA, co-written with Putnam behind the scenes. Putnam thought it was important that the community know all the legal tricks the white CEOs and politicians used to keep them down, so Claude spoke about reapportionment and gerrymandering; he urged them to vote in local elections, to make their voices heard on school boards and in town halls. The TIA got two Black representatives elected to the Police Jury. They made plans to fight for better services in minority neighborhoods, for their cut of revenue sharing, for affirmative action all the way up the ladder.

Putnam continued to keep his wealth a secret. Mildred had released the inheritance from his father to him in 1972. Putnam put all the money into a charitable trust and named it the Mildred Andrews Fund so that it wouldn't bear his name. He again stipulated

the money should be used to fund public sculpture, this time in New York City and Cleveland, Ohio. The artworks, he wrote, "shall be so placed as to benefit especially our underprivileged (ghetto) areas and so chosen as to express their life and outlook." By the mid '80s, Putnam, through stock investments, had grown the fund to \$40 million. "Peter was the most skilled master of finance" he'd ever known, commented the family lawyer. Putnam never touched a penny for himself.

To make ends meet, he took odd jobs repairing radios and shucking oysters. He bought a place where Claude and he could live permanently—a small, one-bedroom apartment with a tiny kitchen and wood paneling on the walls. It was on the main road, next to a vacant lot, but the back door opened out onto the bayou, where they could sit and watch the shrimp boats go by and the moonlight ripple on slow, dark water. "Life is a simple thing," Claude told Peter. "I want to live my life so people associated with me are happy."

Eventually Putnam landed a gig as a night watchman and janitor for the Department of Transportation. "It's clearly the best job I've ever had," he told Spinello on the recordings. "I needed to get other kinds of roots in the community. I think that this position is in some sense symbolically right. Whereas my position as a teacher, you know, symbolically stunk."

The emotion welled up in his voice. "I mean, how could I get in direct relationship to people?" he stuttered. "When there's a big hunk of money ... Even my own prof, who I *loved*, who I did my thesis under ... My mother denied it was going on. She would talk dramatically about committing suicide unless I believed her. I said, 'I believe you.' But, you know, how can I protect myself through a thing like that?"

His voice grew calmer, sadder. "I did kick Wheeler pretty hard in the face for that. I think I was wrong in doing that. The issue is someplace else. I should have been down here sweeping floors."

Putnam knew his mother had destroyed his relationship with Wheeler and had prevented him from getting his work out into the world, but he never blamed her. He believed that her tactics, however much they hurt him, were the rules of behavior she needed to survive in a world dominated by men.



COURTESY OF ROBERT FULLER

“It is especially hard for any woman to be herself,” he once wrote her, “and believe in herself as she is, surrounded as she is with these ridiculous man-made images of how she is supposed to feel and act.”

It’s easy to say why someone is wrong, Putnam said. The hard part is figuring out why they’re right. And everyone is right. Everyone has some central insight, hard won by the consistency-making mechanism of the brain, built of past experiences, cast as motor predictions, a pattern that repeats, sustains itself in the chaos. Our job is to pan for it like gold, sift it into our own nervous systems, reconcile the resulting contradiction, become something new.

“My life’s work, if there is a one-sentence formula for it, is trying to find some path of reconciliation with you,” Putnam wrote her.

Mildred got sick in 1981, and she moved in with her son and Claude. She could have lived anywhere, a mansion in New Orleans, with a staff, like she had back in Ohio, a chef, a housekeeper, nurses. Instead, Putnam

ONE OF THE GREATS

Peter Putnam (far right) with Robert Fuller, baby Karen, and Fuller’s former wife, Ann Lackritz Fuller, in Amherst, Massachusetts, circa 1961. Fuller, who collaborated with Putnam for 10 years, called Putnam “one of the great philosophers of the 20th century.”

The check from the janitor was the largest single gift the environmental group had ever received.

gave her the bedroom, and he and Claude slept on the pullout couch. They made for a strange family, content in the knowledge that they were all there for the right reasons. Putnam and Claude took care of Mildred for three years, until she died in 1984.

Wheeler continued trying to convince Putnam to publish his work. He drove from Princeton to Houma to visit—noting afterward that Putnam was “living as poor as Job’s turkey.” In 1986, Wheeler wrote to Putnam, ending the letter: “There is so much more I’d like to say, but let me sum it all up in one word, gratitude: gratitude to you for all you’ve meant and done over all these years, gratitude to heaven above that you’re still on this earth, still capable—God willing, and in God’s good time—to publish something great.”

December 7, 1987. Putnam swung his leg over his bicycle, like he’d done so many times before.

The drunken swerve.

The screech.

The silence.

ON A FALL AFTERNOON in 2024, I wandered the Princeton campus among the towering sculptures. There was Tony Smith’s abstract *Moses*, Alexander Calder’s *Five Disks: One Empty*, Antoine Pevsner’s *Construction in the Third and Fourth Dimension*, and Jacques Lipchitz’s *Song of the Vowels*. This was the trail of breadcrumbs Putnam left behind.

I watched as other people—students and professors—strolled right past them, as if the sculptures were

invisible. Which was weird, because they’re huge. Louise Nevelson’s *Atmosphere and Environment X* looms 21 feet tall, a steel screen with geometric forms in cut-out compartments that reminded me of a library, or a secret language, or both. Picasso’s *Head of a Woman*, with her stark, cubist angles, weighs in at 20,000 pounds, her rosy cheeks rendered in red quartzite, swirling eyes in black granite.

The Princeton sculptures aren’t Putnam’s only breadcrumbs.

Along Cleveland’s Cuyahoga River is Gene Kangas’ *Hart Crane Memorial Sculpture*, commissioned by Putnam to memorialize the poet, who, after being assaulted onboard a steamship for being gay, jumped overboard and drowned. At Howard University, there’s *A Bridge Above and Beyond* by Richard Hunt, symbolizing the connection between Africa and her children in America, dedicated to “Black womanhood” and “single mothers everywhere.”

In New York City’s West Village, in a sliver of greenery known as Christopher Park, across from the Stonewall Inn, where 1969 riots sparked the beginning of the gay rights movement in the United States, is a sculpture of four figures by George Segal. Two men, standing, appear deep in conversation, one’s arm wrapped around the other’s shoulder; two women sit side by side on a bench, one’s hand on the other’s knee. When Putnam commissioned the piece, he stipulated that the work “had to be loving and caring, and show the affection that is the hallmark of gay people ... and it had to

have equal representation of men and women.” When it was installed, the media called it the “first monument to homosexuals in the United States.”

In the center of the Princeton campus, I came upon *Oval with Points* by Henry Moore, a massive womblike, hollowed-out thing, its bronze now patinated sea-foam green, with two points reaching in toward the center, almost meeting, but not quite. I sat down in the oval and thought about how many things—people, ideas—hide in plain sight, and how many answers to scientific mysteries might be stashed away, junked, or forgotten.

I thought of Wheeler, who helped pick out this sculpture—he described it as a “place for two friends to sit side by side”—and of his lifelong fear that Putnam’s work would be lost.

It’s impossible to know what might have happened if Putnam had gotten his ideas out when he was alive. When he first worked out his theory, Turing was here in Princeton visiting John von Neumann as he was building a stored-program electronic computer, which the press referred to as an “electronic brain.” The comparison between brains and Turing machines was immediately embraced by the scientific community and so entrenched during Putnam’s lifetime that his suggestion that the brain is a “computer of a fundamentally different genus” simply couldn’t compute.

The reason an induction machine—a mind—can do more than a universal Turing machine is because it’s always reaching out into the world. Which was exactly what Putnam himself struggled to do.

Putnam turned his writings into a self-contained room where Ikey could hide and no one would find him. The only one who managed to crack open the door was Claude. “He teaches me how to live outside words,” Putnam wrote. Claude lived in their Houma apartment until he died in 2008.

In Ohio’s Morgan Swamp on the southern shoreline of Lake Erie, among beaver ponds and vernal pools, nestled in a forest of yellow birch and hemlock, are tundra swans and four-toed salamanders, white calla lilies and river otters. In the Animas Mountain range in New Mexico, wild turkeys and long-nosed bats, white-sided jackrabbits and spotted owls, live and breed in 500 square miles of unadulterated ecosystem. On the sandbars and shallows of Nebraska’s Platte River, sandhill cranes swoop down on the floodplain to roost

and forage en route to the Arctic. Some stop in the Ohio wetlands on their return, where they dance in the shadows of soaring bald eagles headed to nest in Putnam Marsh.

All of these lands still exist thanks, in large part, to Putnam. His will stipulated that upon his death, his money—all \$40 million of it—be given to the Nature Conservancy. When the check from the janitor showed up, it was the largest single gift the environmental group had ever received. Putnam would have been happy to remain anonymous. Only the marsh—which he requested be named for his parents—gives him away.

Today, science is beginning to catch up to Putnam. His ideas about the plasticity of the brain and the importance of neural conditioning have become mainstream. Many cognitive scientists are pursuing a theory known as “embodied mind” that emphasizes the central role of motor behavior in cognition and perception, so central to Putnam’s own theory.

At the same time, as Fuller put it, “there’s stuff in Putnam that no one has thought of yet. There’s precious new material for scientists who are on the cutting edge.” That includes not only those working in cognitive science, but also in artificial intelligence and robotics. AI researchers are eagerly searching for models of general intelligence, wondering how it is that humans learn, or have common sense, or deal with novel situations. How humans, as Putnam explained, can perform induction.

I’d spent more than a decade hunched over inscrutable pages under the weight of so much regret about how Putnam’s story had ended. Now, sitting up in the soft curve of Moore’s sculpture, I traced my fingers along the surface where so many fingers had traced it before; in that one spot, the patina was rubbed clean, and the original bronze shone through. Sunlight glistened off the metal, and it dawned on me that maybe Putnam’s work hadn’t been lost. Maybe it was just waiting for its moment. ☺

AMANDA GEFTER is a science writer and the author of *Trespassing on Einstein’s Lawn*. A selection of Peter Putnam’s unpublished papers can be found on her website at amandagefter.com/peterputnam.



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The Extraordinary, Imperiled Science at the End of the Earth

Firing experts in Antarctica couldn't come at a worse time

BY NEIL SHUBIN



IN JANUARY 2019, MY TEAM AND I climbed to the top of an Antarctic peak to hunt for fossils of one of the first fish to walk on land. Our goal was to study the rocky summits of the mountains that protrude through the ice in this region. From this altitude, we could see the barren white plain of the polar ice cap for hundreds of miles in every direction. But we were there for the view below our feet.

Looking down, we saw maroon sandstones, siltstones, and shales that formed 380 million years ago in tropical rivers and lakes. The white fragments of fossil teeth and bones of ancient fish were even visible on the surface. The striking disconnect between the frozen landscape around us and the lush warm world inside the rocks shows how dramatically the planet has evolved over geological time.

But the science of Earth's polar regions goes beyond rocks and fossils. Scientific research at the poles can transform the way we see our entire world, from the origin of the universe, and the extraordinary adaptations of life, to ways that our planet can change during our own lifetimes.

Yet this important scientific exploration faces a barrage of threats. The whiplash induced by DOGE layoffs of federal personnel, court rulings reinstating some of them, and proposals to cut the National Science Foundation's funding by 50 percent, places this groundbreaking and important research and exploration at risk.

These reductions in funding and staffing are coming at precisely the wrong time. The Copernicus Climate Change Service run by the European Union provides regular updates on the state of the planet from data gathered by Earth-observing satellites. Its most recent analysis showed that in February 2024 global sea ice reached an all-time minimum since measurements

Polar ice is disappearing as the U.S. cuts science to understand it.

began in 1978. Arctic sea ice has declined 8 percent below its previously recorded lowest monthly extent, while Antarctic ice has melted to a level 24 percent below its historical average.

As liquid water from melting ice enters the ocean it raises the levels of the seas and changes ocean currents that, in turn, alter coastlines

and weather patterns across the globe. Polar ice is disappearing at a record pace while the United States federal government is cutting the work we need to understand and monitor it.

The scientific enterprise in polar regions depends on the skill, experience, and dedication of staff at Antarctic bases and those stateside. The loss of seasoned polar experts with specialized knowledge in extreme environment operations, ice navigation, and field safety will reverberate through Antarctic research programs for decades, as these skills, developed through 10 to 15 years on the ice, cannot be quickly replaced. We will be left with a dangerous knowledge gap that threatens not only scientific progress but also the safety of future expeditions.

The National Science Foundation runs three bases in Antarctica supporting nearly 1,000 people annually. This operation involves hundreds of researchers leading expeditions to build telescopes at the South Pole, study glaciers at the coast, the geology of the mountains, and ecology on the ice, land, and oceans. These efforts are part of a broader international scientific

NEIL SHUBIN

ON THIN ICE (Left) A group of researchers walking to camp on Mt. Fleming, in Antarctica in 2017.

AT HOME ON THE ICE

The author at Deception Glacier in Antarctica in 2019.

community, with researchers from over 40 nations collaborating across the continent under the Antarctic Treaty System. This remarkable framework of scientific diplomacy ensures that Antarctica remains dedicated to peaceful research, with countries often sharing facilities, data, and expertise to tackle complex global challenges that no single nation could address alone.

The construction and operation of the South Pole Telescope tells the story of the extremes that National Science Foundation staff can go to answer fundamental questions. Unlike a backyard telescope that visualizes the sky in visible light, the South Pole Telescope uses a 30-foot aperture scope to analyze microwave light. Every piece of this machine follows a long supply chain all the way to McMurdo Station on the Ross Ice Shelf, which is the main U.S. scientific station in Antarctica, then hundreds of miles more to the South Pole. And when things break, as they inevitably do in these conditions, spare parts can be thousands of miles away.

The features that make the South Pole Station so challenging are also reasons it is one of the most special places on Earth to put a telescope. Cold, dry, and unobstructed by pollution or atmospheric disturbances, the pole offers a high-resolution view of the sky. The South Pole Telescope is so sensitive that it can measure the oldest light in the universe, dating back to just 380,000 years after the Big Bang, when the

universe was a hot, dense soup of charged particles. It can observe the afterglow of the Big Bang, known as the cosmic background radiation, in unique detail. The clarity of these images reveals patterns in this ancient light that telescopes in other regions of Earth cannot see. These structures help scientists understand how invisible dark matter may be bending space in different parts of the sky.

While Antarctica's unique conditions allow us to peer into the cosmos' distant past, the ice itself holds clues to humanity's future. Polar ice has been our hidden partner, an invisible hand that shapes our world. Despite occupying just 8 percent of Earth's surface, polar regions hold almost 70 percent of Earth's freshwater. Consequently, what happens at the poles doesn't stay at the poles—it sends ripples through Earth's entire system. Every milestone in human evolution—from our species' origins to the establishment of our social structures and technologies—occurred during an unusual time in Earth's history: one with ice at the poles.

For thousands of years, our civilization has developed alongside coastlines, islands, and agricultural zones defined by geographies and weather patterns influenced by polar ice. But warming climates and melting ice bring changes far from the poles. Beaches in the U.S. Gulf Coast have been retreating almost two meters per year in places since the industrial revolution.

A man with a beard and sunglasses, wearing a bright red parka and black beanie, stands in a snowy, mountainous landscape. He is holding a long-handled ice pick. The parka has a circular logo on the chest. The background shows a snow-covered mountain peak under a clear sky.

What happens at the poles doesn't stay at the poles.

The clues inside West Antarctica's rocks reveal how quickly these changes can unfold. This region, comprising about 15 percent of the entire continent, currently lies beneath an ice cap that covers virtually its entire surface. But the rocks along the glaciers tell a different story. Sediments formed in lakes 120,000 years ago show that this area was mostly ice-free during that period. With significantly reduced Antarctic ice, global sea levels stood approximately 14 feet higher than today. What's particularly alarming is that these dramatic shifts in ice coverage and sea levels can occur within timeframes relevant to human civilization, not just on geological timescales of millions of years. These findings suggest that the massive transformations we associate with deep time might unfold within spans that matter to our societies and infrastructure.

Polar environments are an archive of our planet, like a safe containing our planet's heirlooms. When polar regions melt, these vaults open, releasing ancient water, carbon, meteorites, and microbial life into our modern world. The Arctic is warming four to seven times faster than the global average. These changes aren't merely surface phenomena—permafrost that has remained frozen for thousands of years now buckles and collapses.

The Arctic's permafrost holds 1,600 billion tons of carbon—roughly double the amount in today's atmosphere. Thawing permafrost creates a feedback loop of warming that extends far beyond polar boundaries. As the permafrost melts, increasing amounts of carbon inside it are liberated into the atmosphere, heating the planet even more. Microbes released by melting ice and permafrost can infect animals and plants. A 2016 Anthrax outbreak in Siberia spread from the exposed carcasses of animals that were infected and perished over a century ago. Thousands of reindeer were killed, eight people were hospitalized, and one child died.

ICE FISHING

A field crew recovering Devonian Age fossil fish, on Aztec Mountain in Antarctica in 2017.



Antarctica allows us to peer into the distant past and humanity's future.

While there are no known infections from melting ice and permafrost in Antarctica, we are only beginning to understand the microbial richness of the continent. Cores drilled over two miles into the ice have revealed freshwater lakes, some the size of Lake Superior. The biggest of these, subglacial Lake Vostok, even has islands. Satellite images reveal that there may be as many as 600 of these lakes hidden under the ice cap. When researchers analyze the waters of these lakes, they find living things, microbial ecosystems that have been separated from the surface isolated from the sun's energy for millennia. These hidden worlds provide clues for how to search for life in the frozen moons of Jupiter and Saturn.

The cafeteria at McMurdo Station has the feel of the fictional cantina in *Star Wars*' Mos Eisley spaceport. Research groups come and go from all parts of the continent with news of discoveries and stories of life in extreme environments. Tables are populated by different teams specializing in ecology, fossils, glaciers, meteorites, and telescopes as well as the support staff that keeps the science and the base running smoothly.

Returning home from our trip to the Transantarctic Mountains in 2019, the buzz at each table told a similar story. The airstrip that supplies McMurdo Station had to be moved farther from the base because of thinning ice. The groups doing long-term ecological monitoring of the valleys outside of McMurdo reported sudden declines of important species. The roundworm *Scottinema lindsayae*, which makes up a vast majority of the nematodes in the Dry Valleys, has seen its populations crash as the valleys have grown warmer and wetter in recent years. Glaciologists returning from the West Antarctica Ice Sheet talked about how warm water from the Southern Ocean was seeping under coastal glaciers, melting them from below. If this coastal ice collapses, vast amounts of ice from the interior of the West Antarctic Ice Sheet could enter the Southern Ocean, and raise global sea levels, in the coming decades.

Across dinner tables, disciplines, and research sites, stories converged on a clear and sobering reality: Antarctica's ice knows no politics, yet it faithfully records the consequences of our choices. From the origin of the universe to the future of our planet, polar science holds a chronicle of our ever-changing world. ☺

NEIL SHUBIN is an evolutionary biologist whose team discovered *Tiktaalik roseae*, the iconic fossil fish that was among the first to walk on land. His search for fossils has led him to all seven continents including over three decades in the Arctic and Antarctica. An elected member of the U.S. National Academy of Sciences, he is a professor at the University of Chicago and author most recently of *Ends Of The Earth: Journeys to Polar Regions in Search of Life, the Cosmos, and our Future*.

NEIL SHUBIN





When Did I Start Getting Cancer?

An environmental chemist investigates the origins of her leukemia

BY ALISON SPODEK

IT'S IMPOSSIBLE TO KNOW exactly when each of the five mutations happened. When, deep in my marrow, one thing after another went awry, and divided my life. Like all people who have been ill, my life is split into Before and After. The mutations must have happened in the Before, because that's how leukemia works.

Did a mutation occur the summer Before, when my gallbladder inexplicably started to act up, when I got a surprisingly terrible case of hand-foot-mouth virus for an adult? Perhaps one occurred in college, silently changing my future while I took my first organic chemistry lab, casually flirting with my graduate TA and being careless with a solvent. Maybe the first mutation occurred when I was 2 years old, wearing footie pajamas soaked in flame retardant, as was the norm in the mid 1970s. Is it possible, even, that the mutation happened generations before I was even born, perhaps when my grandmother worked in her family's dry-cleaning shop, the chemicals triggering a change deep in one of her cells that eventually led to her death, my father's, and nearly mine? Buried in these questions is, of course, the deeper question of why. It is even more unknowable than when.

ILLUSTRATION BY MARIA FEDOSEEVA

Since my diagnosis in March 2013, science has leaped forward in understanding how leukemia, or blood cancer, forms. All blood cells are born from a particular type of stem cell found in the bone marrow called a hematopoietic stem cell. Over five generations, hematopoietic stem cells differentiate into red cells, carrying oxygen; platelets, allowing clotting; and the myriad types of white blood cells, mounting immune responses.

Diagrams of this process look like a family tree, with one ancestor spawning many different descendants. The ancestor cell is pluripotent, meaning it can form all types of blood cells; each generation down is a little less powerful, and a little more specific. Some generations become stem cells for one or more specific cell types. The final generation are our blood cells that are constantly dying and being replaced, unable to have offspring of their own. The constant cycle of blood death and replacement makes blood donation possible and explains why every person has, and needs, hematopoietic stem cells.

The process of each generation of hematopoietic cells becoming something new relies on the central dogma

of molecular biology. This dogma states that genes are found on DNA and encode instructions; when these instructions are transcribed, they become RNA, which in turn is translated into proteins. If the gene, found on DNA, is a blueprint for a doghouse, the RNA is the shopping list you take to the hardware store, and the protein is the doghouse you build. Different genes encode different proteins (building projects, like bookshelves and tables), such as enzymes used in digestion, collagen found in hair and nails, and even proteins that interact with DNA, turning on and off genes for yet other proteins. Imagine if you could build something that would then influence the blueprints for your next project!

Mutations are copy-editing mistakes in the DNA instructions, and happen frequently as cells divide and differentiate. Many mutations get corrected quickly by the mind-blowingly complex self-correction systems within our cells. Some do not. Some mistakes are random. Some mistakes are prompted by exposures to DNA-damaging substances, like solvents and radiation. Some mistakes don't matter, while others have profound consequences—like leukemia.

ONE: THE CENSOR

In February 2013, when I first became ill, breathless, pale, and feverish, no one could have even tried to answer the questions of when the first mutation happened, or what it was. But in August, just six months later, while I was hospitalized for a terrifying bout of pneumonia that occurred after chemotherapy annihilated my immune system, a group of scientists submitted a paper to *Nature* that began to answer this question. By the time the paper was accepted for publication in January 2014, I had received a hematopoietic stem cell transplant, often referred to as a bone marrow transplant. This transplant was the brutal, lifesaving process in which the contents of my bone marrow were completely obliterated by chemotherapy and radiation. The goal was to destroy every hematopoietic stem cell in my body, most especially those harboring these mutations, and then replace them by infusing

healthy stem cells from an unknown donor through a line in my chest.

The authors of that *Nature* paper showed that acute myeloid leukemia, the type of leukemia I had, begins with a mutation in one of the hematopoietic stem cells, decades before illness. Slowly, over these decades, some perverse version of survival of the fittest means that the clones of this stem cell overtake the bone marrow, and all the blood formed thereafter shares that mutation.

This mutation, found to lay the groundwork for acute myeloid leukemia, is in a gene named *DNMT3A*. *DNMT3A* codes for a protein that controls hematopoietic stem cells' differentiation into specialized blood cells. It does this by tagging the genes of these cells, indicating which genes to activate and which to suppress. Thanks to this powerful protein, which acts as a censor, one daughter of a stem cell can read

only the instructions to become a red blood cell, while another daughter can read only the instructions to become a platelet.

Although this mutation is passed from one generation of cells to its daughters, it is not passed from one human generation to the next, so I can let my dry-cleaning ancestors off the hook. Instead, I imagine that a mutation to *DNMT3A* occurred when I was a child. This mutation gave rise to a protein that didn't censor the cell differentiation genes in quite the

expected manner. This alone wasn't enough to cause acute myeloid leukemia, but it was a start.

Because the importance of this gene wasn't known to science when I was first ill, my bone marrow was never examined for this mutation. Its presence or absence in my body is unknown, and now probably unknowable. This mutation, and all that followed, have been eradicated from my blood and my marrow, overtaken by the benevolent invaders of donor cells.

“Just a little cancer” is as ludicrous as “just a little pregnant.”

TWO: THE ERASER

Leukemia is a surprisingly common diagnosis, afflicting more than 1 in 100 people in the United States. This is due in large part to the relatively small number of genetic mutations required to start leukemia. Some tumors in the lungs average more than eight mutations per million letters in the genetic code; acute myeloid leukemia averages fewer than 1 mutation per million letters. An average of only 13 mutations are found in leukemia patients' cells, and of those, five mutations are found on average in the coding regions of DNA that make proteins.

TET2 is another gene that codes for a protein that in turn modifies the activity of other genes; it is the first domino in an elaborate Rube Goldberg machine. When mutated in a hematopoietic stem cell, it can persist in the marrow for decades. If *DNMT3A* makes the censor protein, blacking out genes so that only the appropriate differentiation genes are

read, *TET2* makes the eraser protein, following behind *DNMT3A* and removing the censor marks willy-nilly.

It was January 2013, Martin Luther King Jr. Day. Before. I was supposed to march in honor of Dr. King, but the weather was cold, and I had a chill in my bones I couldn't shake, so instead I stayed home and made zucchini carrot mini-muffins for my children, ages 1 and 5. The 5-year-old thought the muffins were pretty cute, and we took some whimsical pictures of them with little Lego people scaling them like mountain climbers.

TET2 was suspected in my leukemia, and its presence bodes ill for the long-term. Since the genetic test for it wasn't approved until after I was deeply and gratefully in remission, we'll never know. I imagine that by that chilly January Before, it too was present in my body, slowly setting the stage.

THREE: THE SHEPHERD

A few weeks later, President's Day 2013, when it was still Before, my husband and I met some old friends for dinner halfway between our homes, about an hour drive for each couple. We ordered fish and wine, and talked about our children and our jobs, as people in their mid-30s do. By the time the waiter asked if we wanted dessert, I was shivering and feverish, chilled to the bone and feeling deeply unsettled. My husband paid our share and we drove home quietly.

By this time, my hematopoietic stem cells must have been misreading instructions; instead of five generations to form perfect daughters, these stem cells were rushing, pushing out immature and dysfunctional blood cells known as blasts. Between a malfunctioning censor protein and a misbehaving eraser protein, the genetic instructions in my marrow had become a garbled mess.

FOUR: THE DRILL SERGEANT

In early March, 2013, still Before though barely, my marrow was full of blasts, trying to skip a generation or two of differentiation and bursting free into my blood, unbeknownst to me. I walked up the two flights of stairs from my office at Vassar College to a colleague's office and had to sit down when I got there, I was so winded. Just a cold I can't shake, I told her, but she gave me a puzzled, worried look nonetheless.

After another week I was teaching my chemistry classes sitting down, finding that I no longer had the breath to speak and stand at the same time. What was unknown to me then was that the deep fatigue was due to a steady decrease in my oxygen-carrying red blood cells, meaning no matter how fast or hard I breathed, I simply could not get enough oxygen. The immature white blood cells, those blasts, were dominating my marrow, pushing out the ancestors of all other types of cells.

Two generations below the hematopoietic stem cells, in a precursor cell for certain white blood cells called a GPM, the most crucial mutation had already occurred. This mutation was in a gene called *NPM1*, encoding a multifunctional protector and shepherd protein called nucleophosmin. Nucleophosmin shepherds cells through their replication, allowing the GPMs to multiply and become functional white blood cells known as myeloid cells. By mid-February, my nucleophosmin was also out of commission. Healthy nucleophosmin acts as a shepherd in part by protecting tumor-suppressor proteins. If nucleophosmin is the shepherd, these proteins are the sheepdog. Without the shepherd, the sheepdog can be distracted, and the sheep (those crucial myeloid cells) can be attacked by a roaming coyote.

The last Wednesday Before, I drove home and was so exhausted by the 30-minute drive that I vomited as soon as I pulled in. I walked upstairs, crawled into bed, and while my husband got the kids to sleep, I called my best friend. I know it's supposed to be hard, I said, weeping. With the kids. The job. But I don't think it's supposed to be *this* hard. I got off the phone and started Googling my symptoms. Recurrent fever. Swollen lymph nodes. Fatigue. Pale skin. I took note of the terrible list of possible diagnoses and told no one.

That Friday I had my blood drawn, and that Sunday the doctor's office called me, even though they were closed. She had seen the results. Your blood counts are very off, she said. You need to go to the emergency room. With those words, the Before ended. I wouldn't leave the hospital for the next seven weeks.

The next day I had my first bone marrow biopsy, in which a needle so large it looked like

Maybe the first mutation occurred when I was 2 years old, wearing footie pajamas soaked in flame retardant.

a leather punch was pushed into the back of my pelvis. It's a procedure nearly as dreadful as it sounds. Under a microscope, the abnormalities of my cells were immediately evident; there were far too many of them crowded together chaotically, and at least one in five was a large lumpy blob—a blast. It wasn't until my second biopsy, less than a week later, at a more specialized hospital, that anyone would start looking for the genes that had started this all dozens of years ago and maybe, just a few weeks before.

One of the most significant findings in my marrow was an absence. Not just the absence of red blood cells, making it hard for me to breathe, or the absence of platelets, making me bruise and bleed easily, but the absence of a mutation. The *FLT3* mutation is found in almost a third of acute myeloid leukemia patients: It is one of the most common mutations, and the most dreaded. The protein made by *FLT3* is a signaling protein, telling the cell when to grow, to divide, to survive, and to die; it's a drill sergeant, controlling each movement of the developing white blood cells. In its mutant form, it's a deranged drill sergeant, marching its troops right off a cliff. The mutant form of *FLT3* is described in one paper as a "poor prognostic indicator."

When I first started chemotherapy I participated in a clinical trial, swallowing a shot glass of bitter clear liquid each morning. It felt like a little offering of hope from the future. More concretely, it was a *FLT3* inhibitor, a muzzle for the deranged drill sergeant. When we received the results of my genetic testing telling me I did not have the *FLT3* mutation, I was oddly disappointed to no longer receive my futuristic daily cocktail. But my overwhelming sense, in a season in which I received so much bad news, was profound relief at yet worse news avoided.

HER OWN SLEUTH After she was diagnosed with leukemia, Alison Spodek, an associate professor of chemistry and Director of Environmental Studies at Vassar College, became determined to uncover the genetic suspects behind it.



The genetic instructions in my marrow had become a garbled mess.

FIVE: THE BOUNCERS

Over the next two years I had almost two dozen more bone marrow biopsies. With the early ones, we asked, *How many blasts are left? Did the chemotherapy work? Are the healthy blood cells growing back?* More sensitive lab tests are necessary to look for mutations rather than cells, so when the answers to the first questions were encouraging, the pathologists started looking for *NPM1*, the most characteristic mutation of my disease. Its absence would mean we were seeing only donor cells. With these biopsies we asked not, *Has the disease returned* but, *Will the disease return?* There's a comfort in the idea that these tests can answer that question, and of course, the deeper question underneath: *How long do I have?* The answer to this question, like the why, is fundamentally unknowable.

I had another biopsy in March 2014, one year into the After. This was six months after my bone marrow and hematopoietic stem cells were obliterated by high dose chemotherapy and radiation, six months after I received hematopoietic stem cells from a stranger. This

stranger, a woman across the country, gave me a new set of cells, and with them their functions: censors, erasers, shepherds, and drill sergeants.

Like the previous dozen or so biopsies, the cells appeared normal, but unlike anything in the past 10 months, the genes did not. *NPM1* was detected in my marrow, a flaw reasserting itself. I asked my doctor, hands and feet icy from terror, whether the disease was returning. We don't know, she said. Some mutations, if they reappear, mean the disease is back. Others are meaningless. What about *NPM1*, my mutation? She told me she didn't know—no one did.

More than 10 years later, I combed my medical records and saw what she didn't tell me then. The return of *NPM1* is a sign of "minimal residual disease," the medical term for "just a little cancer." It's as ludicrous a proposition as "just a little pregnant."

The best explanation for what happened is that at least one single, microscopic hematopoietic stem cell with my mutations—*DNMT3A*,

TET2, *NPM1*, and unknown others—made it through all the treatment. The very malfunctions that made that cell deadly also made it powerful, and it grew once again, multiplied enough to be detected on the lab test.

This time, six months post-transplant, I had backup. The donor hematopoietic stem cells had colonized my marrow and produced generations upon generations of healthy blood cells. These were the bouncers, waiting at the door of the night club. When someone inside got rowdy, the bouncers kicked them out. The healthy white cells now recognized my new blasts for the enemies they were and destroyed them.

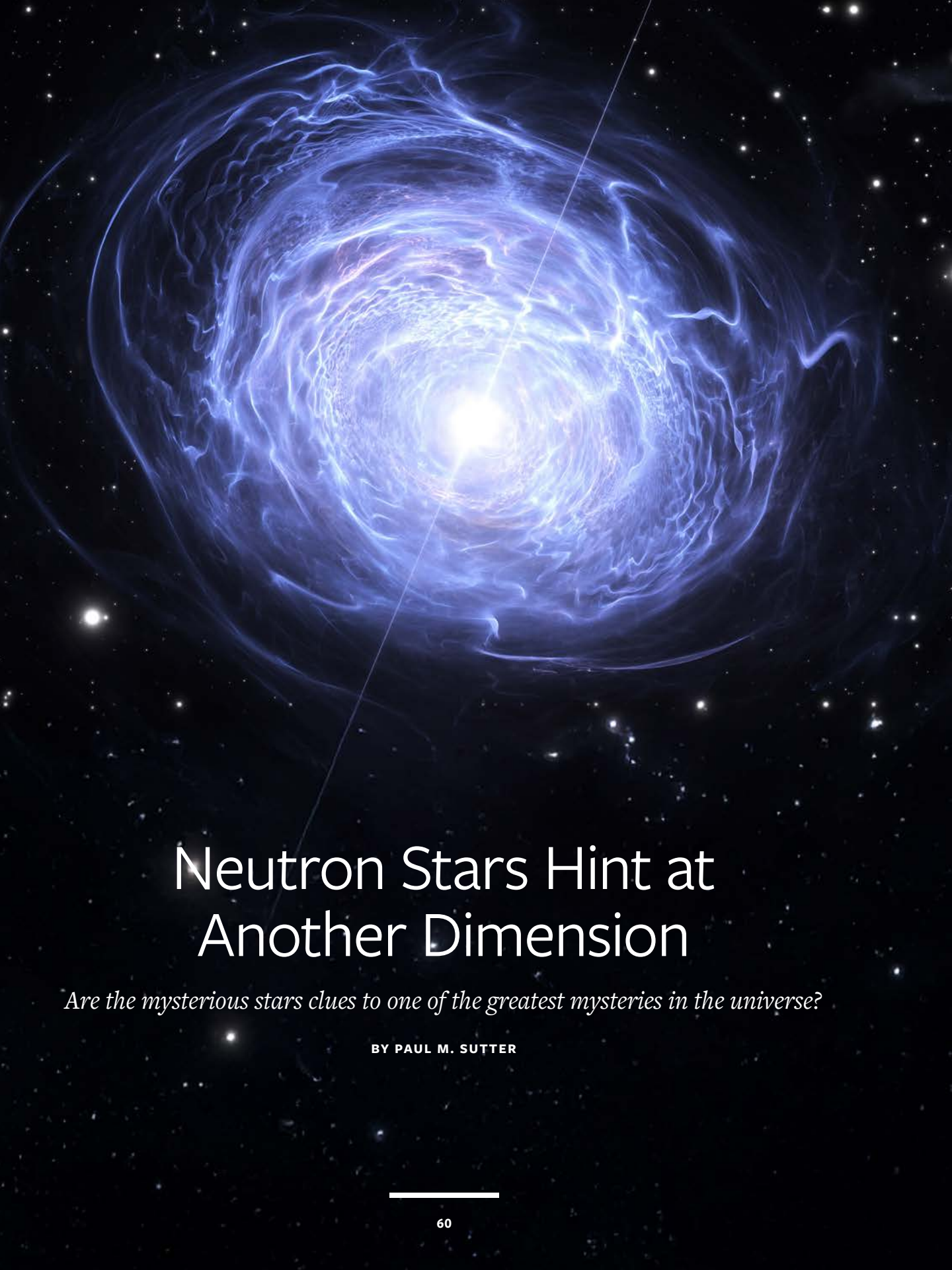
I had my 25th, and very last, bone marrow biopsy nearly two years into the After, the week before another Martin Luther King Jr. Day, this one in 2015. That was 10 years ago, and I am cured.

A patient diagnosed with acute myeloid leukemia today could be tested for as many as 50 mutations. Each gene tested gives a little information to the patient, a better sense of risk. But it can't answer the most fundamental question: *How long do I have?* No one knows the answer to that question—not doctors, or patients or people living in the Before, blithely unaware of the possibilities.

More importantly, each new piece of information gives the possibility of a more tailored treatment, of drugs that target each gene and protein. The *FLT3* inhibitor I briefly took as part of the experimental trial has come to market and is muzzling rogue drill sergeants for patients every day.

The standard of care, however, remains a stem cell (bone marrow) transplant. For patients like me, nothing works as well as wiping the marrow clean and bringing in a new army of cells from another person. No one can predict the future, but I don't imagine this will change anytime soon. No matter how much genetic knowledge we gain, we still need each other. ☺

ALISON SPODEK is an associate professor at Vassar College with a focus on environmental chemistry and pollution. She lives in Beacon, New York, with her husband and two children.



Neutron Stars Hint at Another Dimension

Are the mysterious stars clues to one of the greatest mysteries in the universe?

BY PAUL M. SUTTER



IN THE MID 19TH CENTURY, a strange idea was growing heavy in the ether: There might be dimensions beyond the three we experience. To some—including eminent scientists of the day—these were the realms of spirits and the supernatural, accessed through tabletop seances. To Charles Hinton, a British mathematician and science-fiction writer at the time, it was something that could be puzzled out, modeled in things like his “tesseract” four-dimensional cube.



In the intervening century and a half, spiritualism and mainstream science having parted ways, the serious search for these extra dimensions has only intensified. Lately, physicists have proposed a new way to “see” into a new dimension—by looking deep into the hearts of collapsed, dead stars that have been behaving strangely.

The concerted scientific journey into extra dimensions began with Hermann Minkowski, Einstein’s former teacher, who realized that “space by itself, and time by itself, have vanished into the merest shadows” and that only a unification of them, spacetime, exists. Spacetime means that the universe truly is four-dimensional, just that one of the dimensions is that of time, rather than an additional one of space. One extra dimension discovered.

But might there be more?

Beginning in the middle of the 20th century, scientists began to speculate that there might indeed be more to the universe. And that speculation was born from an unlikely source: the astounding weakness of gravity.

The force of gravity is weak. And not just a little bit weak. It’s so much weaker than the other three fundamental forces—electromagnetism and the strong and weak nuclear forces—that it’s almost impossible to provide analogies. Gravity could be a trillion trillion times stronger than it is, and it would still be the weakest of the forces by many orders of magnitude.

The origin of the strengths of the fundamental forces of nature remains an outstanding problem in physics. We don’t know why electromagnetism has the strength that it does, why the strong force is so strong, and why the weak force is so weak. But gravity sticks out like a sore

If the “braneworld” hypothesis is true, then we have no idea just how magnificent the universe is.

thumb. All the other forces may be weaker or stronger than the others, but they’re at least in the same ballpark. Gravity isn’t even on the same planet.

The thinking goes that if we can understand why gravity is so especially weak, we might be able to use that as a way to discern why the other forces are so strong.

And maybe the answer lies in an extra dimension.

In 1999, theoretical physicists Lisa Randall and Raman Sundrum proposed a wild restructuring of the cosmos. In their model, what we call the universe is really a “brane”—a three-dimensional expansion of our usual conceptions of a membrane.

But our brane is not the entire universe. In their model, it’s embedded in something much larger, dubbed the “bulk.” The bulk has an extra spatial dimension, and our brane universe floats along inside of it like a piece of paper caught in the ocean currents. We can’t see the bulk, touch the bulk, experience the bulk, or otherwise interact with the bulk because our entire universe—all the particles and forces of nature—are restricted to life on the brane. It stretches the mind in a way that’s almost





WEIRD VIBRATIONS

Neutron stars' super-strong jets of radiation might be made narrower by an additional dimension we haven't otherwise been able to detect. A new X-ray telescope from the European Space Agency might reveal more.

a throwback to the early days of the search for an extra dimension—when, in 1884, Edwin Abbot published his satirical book *Flatland: A Romance of Many Dimensions*, in which geometric figures inhabit a two-dimensional universe that is rocked when a sphere, a three-dimensional object, intersects with their world.

The brane-bulk model is a speculative idea for sure, but a fun one. Like the beleaguered citizens of Flatland, if the “braneworld” hypothesis is true, then we have no idea just how magnificent the true extent of the universe is.

And so it's worth finding ways to investigate whether this literally outside-the-box idea has any merit—to find if we can poke our heads into the fifth dimension. Physicists just need some way to pierce the veil of the brane and peer into the realm of the bulk. To try this, they have enlisted gravity.

Gravity, the thinking goes, can escape our brane and extend into the bulk. That explains why it's so weak. All the other forces must play in only three spatial dimensions, while gravity can extend itself out to four, spreading itself much too thin in the process.

Physicists can try to peek into the extra dimensions of the bulk at tiny scales using experiments that

can fit on a tabletop—granted in setups much different than 19th-century spiritualists' gatherings. These exquisite devices test the strength of Earth's gravity as microscopic objects move over minute distances. They then compare the movements of those particles to see if there are any deviations from the gravitational phenomena predicted by Einstein's theory of general relativity. So far, no evidence for extra dimensions has emerged from those experiments.

So other physicists have turned away from the tabletop and to the stars for answers. Specifically, neutron stars. These are the ultra-dense leftover cores of giant stars. This tremendous density makes them excellent laboratories for studying gravity under extreme conditions, where it might crack open our historical models.

If our running knowledge of gravity is mistaken, and our universe is really a brane floating in the bulk, then it might just show up in ever-so-slight differences in the behavior of neutron stars. This is because the brane-bulk interaction might change how gravity is working, ever so slightly—but just enough for us to detect it in those extreme environments.

In particular, the extra dimension could make itself known by supplying an extra source of energy,





Neutron stars are perhaps the most exotic objects in the entire universe known so far.

something that physicists have dubbed “dark radiation,” and an extra source of pressure, called “dark pressure.” Dark radiation acts like an invisible form of light that can carry and transport energy; dark pressure is an extra source of support against the usual inward pull of gravity. Both of these appear as terms in the modified equations of gravity, additions that are absent in our usual conceptions of general relativity, our current best treatment of the gravitational force.

Which brings us back to neutron stars. Neutron stars are perhaps the most exotic objects in the entire universe known so far—rivaling even black holes. They are best described as atoms the size of cities, composed of ultra-dense nuclear matter compressed into even more incomprehensible densities. A single teaspoonful of neutron star guts would outweigh the Great Pyramid at Giza. Their gravities are so strong that they can force light to orbit around them. If the twin phantoms of dark radiation and dark pressure from the additional dimension are in fact changing how gravity works, it could influence how compact neutron stars can be, how efficiently they radiate heat, and even the arrangement of their internal composition. Which would be helpful because some neutron stars seem to be acting in odd, unexpected ways.

In 2019, the LIGO detector, a pair of kilometer-long laser interferometers in Louisiana and Washington, measured gravitational waves emanating from the merger of a black hole with ... something else. The black hole had a mass of around 23 solar masses. Its companion had a mass of only 2.6 solar masses. That’s far too small to be a black hole ... but also a little too big to be a neutron star. Which sent physicists searching for an explanation for the massiveness of the other, mysterious object.

Recent calculations have shown that an extra dimension, in the form of bulk, can potentially explain the extra heft of that companion. It’s not a slam-dunk case, but it is an intriguing hint.

Other recent observations of binary neutron star systems have revealed odd fluctuations in brightness that are almost, but not quite, perfectly regular. While researchers think that the complex gravitational interaction between the neutron stars and the material surrounding them gives rise to these almost-periodic fluctuations, they haven’t been able to pin down the exact cause. Some theorists have proposed that it is nothing less than the brane-bulk interaction that changes gravity just enough to create this off-beat rhythm.

And even beyond gravity, other forces might also be giving hints of this extra dimension. Neutron stars can host the strongest magnetic fields in the known universe, boasting strengths up to quadrillions of times greater than the Earth’s field. These magnetic fields are strong enough to literally rip apart anything that wanders too close. As the neutron star rotates, the spinning super-strong magnetic field creates an electric field, which spirals into a beam of radiation that jets out of the axis of the star. Physicists discovered that the braneworld would weaken the interplay of magnetic and electric fields enough to lower their strength, leading to a narrower beam of radiation. While this particular hypothesis hasn’t been tested yet, it could be soon with a new X-ray telescope from the European Space Agency.

This effect cannot be replicated in the laboratory, as attempts to create magnetic fields even billions of times weaker than these make all of our equipment melt. So physicists will continue to keep their eyes on the stars for a window into an extra dimension. ☺

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My Visit with My Dead Father's Brain

What I discovered about my dad and myself at the lab where his brain resides

BY RACHEL LEHMANN-HAUPT





IN A BRISK JANUARY EVENING this year, I was speeding down I-295 in northeast Florida, under a full moon, to visit my dad's brain. As I drove past shadowy cypress swamps, sinewy river estuaries, and gaudy-hued billboards of condominiums with waterslides and red umbrellas boasting, "Best place to live in Florida," I was aware of the strangeness of my visit. Most people pay respects to their loved ones at memorials and grave sites, but I was intensely driven to check in on the last remaining physical part of my dad, immortalized in what seemed like the world's most macabre library.

Michael DeTure, a professor of neuroscience, stepped out of a golf cart to meet me. "Welcome to the bunker. Just 8,000 of your quietest friends in here," he said in a melodic southern drawl, grinning in a way that told me he's made this joke before. The bunker is an indiscriminate warehouse, part of the Mayo Clinic's Jacksonville, Florida, campus that houses its brain bank.

DeTure opened the warehouse door, and I was met with a blast of cold air. In the back of the warehouse sat rows of buzzing white freezers. DeTure pointed to the freezer where my dad's brain sat in a drawer in a plastic bag with his name written on it in black Sharpie pen. I welled up with tears and a feeling of intense fear. The room suddenly felt too cold, too sterile, too bright, and my head started to spin. I wanted to run away from this place.

And then my brain escaped for me. I saw my dad on a beach on Cape Cod in 1977. He was in a bathing suit, shirtless, lying on a towel. I was 7 years old and snuggled up to him to protect myself from the wind. He was reading aloud to my mom and me from Evelyn Waugh's novel, *A Handful of Dust*, whose title is from T.S. Eliot's poem, "The Wasteland": "I will show you fear in a handful of dust." He was reading the part about Tony Last, an English gentleman, being imprisoned by an eccentric recluse who forces him to read Dickens endlessly.

The room suddenly felt too cold, too sterile, too bright, and my head started to spin.

The memory calmed me down. The brain in a freezer bag, after all, was not my dad. My dad was Christopher Lehmann-Haupt, a *New York Times* book critic who spent decades, from the 1960s to the '90s, shaping literary culture with an authority that made authors both revere and fear him. At home, my mom, Natalie Robins, a poet and author, called him “Crit,” her pet name for the tough critic who was most tough on himself, reading books late into the night, clinging to a glass of Christian Brother’s brandy, reclined in a broken swivel chair.

As we walked through the freezer room, I continued to think about my dad’s brain, nestled in a shelf among other frozen brains, and my fear gave way to a strange mix of wonder and sadness. The once active neurons that fired electrical and chemical signals from axons to dendrites inside the crevices and folds of the left frontal lobe, home to the language center, were now quiet. The memories produced in the hippocampus were now frozen. These parts worked in concert to convert my dad’s experiences into the language of more than 4,000 essays and book reviews, two novels, and a memoir about his life as a New York Yankees fan.

Beginning when he was in his 70s, my dad loyally volunteered for a longitudinal study on the aging brain run by the Albert Einstein College of Medicine. He would drive from home in the Riverdale neighborhood of the Bronx to a nearby lab at Montefiore Hospital every few months to take written tests and participate in interviews to evaluate his memory and mental agility. The purpose was to contribute to the body of scientific data on neurodegenerative diseases, such as dementia and Alzheimer’s disease, which *Nature Medicine* recently predicted could double in the United States over the next 35 years to 1 million new cases annually. My dad became so inspired by the study that he agreed to donate his brain for further research when he died.

**FATHER AND DAUGHTER**

The author and her dad, Christopher Lehmann-Haupt, an influential book critic, at home in New York City in 1972. “I have always wondered about my dad’s mind,” Rachel Lehmann-Haupt writes today.

My dad was a *New York Times* book critic whose authority made authors revere and fear him.

I came to the brain bank because I wanted to learn how his brain was contributing to science. And I came for my own reasons. I have always wondered about my dad's mind, how it worked, why it told stories, and how our family stories going back generations shaped his life. What I learned was emotional and startling, particularly when the neuropathologist explained to me what my dad's brain revealed about how he died. My visit helped me find the deeper connection with my dad that I had yearned for growing up.

AS MY DAD WAS TAKING TESTS about his brain at the Albert Einstein College of Medicine, he was writing a lot, working on a memoir about his experience working for *The New York Times* and the Jewish side of his family that he knew little about. He was calling it *Re-View*.

He had been in therapy in the last decade of his life, working out family trauma related to his parents' tumultuous divorce during the time his father moved the family to Berlin after World War II. My grandfather, Hellmut Lehmann-Haupt, was an expert on rare books and the Gutenberg printing press. After the war, he took an assignment from the Monuments, Fine Arts, and Archives program, which the Allied powers had set up to hunt for artistic and cultural artifacts that had been stolen by the Nazis. My dad wrote that "my father's assignment was to nurture and to revive the artists that Hitler and his henchmen had trod down for being 'degenerate,' their characterization of any imagery that deviated from their narrow totalitarian ideal of the human form."

My dad also wrote about his relationships with many authors of his era: William F. Buckley Jr., Robert Caro, John Cheever, E.L. Doctorow, Joan Didion, Nora Ephron, Philip Roth, Lillian Hellman, and critic Lionel

Trilling. He wrote that he and my mom Natalie “got so close to Bill and Pat Buckley that once when they were squabbling, which they did very often, Natalie was able to take their hands and say, ‘Now, children.’ About our being friends with both Hellman and Trilling, mortal enemies, Mailer once remarked to Natalie, ‘Someday, after you die, especially if you go to Hell, you’ll have to choose between those two.’”

My dad was in relatively good health for his age, but he spent many years writing while chain-smoking unfiltered Camel cigarettes. At 45, he had a silent heart attack, so he quit smoking, began taking statins and took up jogging around the neighborhood.

When he turned 80, he would occasionally give me updates on his brain study, I think mainly to assure me that he didn’t have dementia. He was the kind of parent who never wanted to become a burden to his children. I mostly listened because I hoped hearing about the study would help me get to know him better. We were close, yet he was emotionally distant like many men of his generation. Getting his attention always felt like a struggle. He seemed to soften in those years and enjoy life more. He even gave up drinking brandy, and one day, I saw him doing deep knee bends in the kitchen. He loved being a grandfather and wanted to stay healthy to extend his time with us.

Then, one evening, in late October of 2018, at the age of 84, he suffered a stroke. My mom called me from an ambulance rushing from their Riverdale home to the Columbia Presbyterian emergency room on West 168th Street. Through her tears, she described how he had made a stir fry for dinner and then returned to his study to write. An hour later, she came downstairs to show him a photo of my son on her phone and found him unconscious and paralyzed in front of his computer.

In the emergency room, the doctors discovered that soon after he sat down at his desk, a blood clot was released from his heart and traveled up a cerebral artery into his brain, stopping blood flow. They rushed him into endovascular surgery to clear the clot, but when he woke up, he could no longer speak. When the nurses handed him a pen, his hand could no longer form letters. It was a poetic and cruel twist of fate for a man whose life was shaped by words and stories. I didn’t know what was worse: his impending death or that we couldn’t talk about what was going through his mind. “Be logical,” he always told me, when I went to him for advice, but logic was lost on me now. I just longed for his comforting words.

Over 10 days, our family watched him fade away, and soon, we made the collective decision to turn off the machines that were keeping his heart pumping. My dad had made it clear in his medical directive that he didn’t want “death staved off” if he no longer could live independently. In those hours, my mother, brother, and I were making that decision, I didn’t want to let go, but then I placed a pen in his hand to see if he could still hold it, and he couldn’t. His literary brain had lost language and could no longer produce the words that drove his life and defined so much of his identity. I knew then it was time to say goodbye.



A FOREIGN DISCOVERY

At his neuropathology lab at the Mayo Clinic, Dennis Dickson dissects a brain. When Dickson performed the autopsy on the author's father's brain, he found it contained a damaging "foreign material."

I LEFT THE COLD BRAIN BANK and piled into a golf cart with DeTure and Dennis Dickson, the neuropathologist who performed the autopsy of my dad's brain. We zipped past modern glass research buildings, many of which contain a vast art collection that includes a chandelier of 170 glass-blown flowers by Dale Chihuly and a triptych of animal paintings by Andy Warhol called "Endangered Species." There were bronze nudes on lawns donated by the wealthy families of former patients and a human-made lake dotted with palm trees punctuated by a fountain.

Dickson and I sat in his small office just down the hall from the dissection lab. In a modest, adroit Midwest manner, Dickson looked at me. "It's rare for a loved one to come to visit a brain. Maybe we get one a year, usually a benefactor who donated." He walked me through how my dad's brain got to this unusual library. In New York, a pathologist removed his brain, and half was fixed in the chemical formalin, and the other half was frozen, and then both were flown down to Florida in a box.

COURTESY OF THE MAYO CLINIC

The formalin-fixed half of his brain was set in a refrigerator to be dissected and sampled in the “brain-cutting conference.” Dickson cut standardized sections from the major brain areas while Ph.D. students read out the donors’ cause of death. A neurohistologist—a specialist who studies the microscopic anatomy and connections of the brain—embedded the tissue sample into paraffin wax and applied pink and purple dyes to make slides resembling fibrous stained-glass windows. These slides are used to look for specific pathologies under a microscope and digitized in a scanner so researchers can view the tissue on a large scale on a computer screen to analyze the cells. Brains are de-identified so scientists don’t know who the donor was.

Dickson told me that the report found no signs of Alzheimer’s disease. That jibed with what Richard Lipton, the head investigator of the Einstein study, had told me about my dad. “Our staff thought he was amazing, articulate, and kind,” Lipton said. “I have rarely seen people at age 84 with verbal memories that good.” It was hypertension and atherosclerotic disease that caused the blood clot to blast through his brain. I thought about his ashtrays filled with smashed cigarette butts, his volcanic reactions to stress, and love of fatty foods.

Dickson said my dad had two contiguous strokes in the temporal and frontal lobes, the location of the control centers of language. The second stroke destroyed almost the entire temporal lobe, including the medial temporal lobe structures such as the amygdala, where emotions get processed, and the hippocampus, where memories form. The temporal and frontal lobes also hold the language control centers, Broca’s and Wernicke’s areas. “The affected regions are very much in the business of expressive and receptive language, both understanding what’s said to you and being able to formulate semantics with meaningful sentences,” Dickson said.

Because my dad could understand us in his final 10 days in the hospital, but he couldn’t speak or read, they concluded that he had Broca’s aphasia. In 1861, French neurosurgeon and anthropologist Pierre Paul Broca studied patients with language deficits and aphasias. He discovered the role of the left frontal lobe in speech production. It was the first time a scientist showed that the two hemispheres of the brain, though seemingly symmetrical, have different functions. He famously said, “*Nous parlons avec l’hémisphère gauche*,” meaning “We speak with the left hemisphere.”

I was curious whether, when he was dying, even though he couldn’t express himself, my dad’s memories were still in there. Dickson said he couldn’t speak to that. Later, I spoke to John Crary, professor of neuroscience, artificial intelligence, and human health at the Icahn School of Medicine at Mount Sinai, who runs its brain bank. He told me that while aphasia can impact the ability to access semantic memory and create words, that memory itself is generally still present. Although my dad could not express his thoughts and memories, I felt relieved knowing they were still there in the last 10 days we were all together.

THERE WAS SOMETHING ELSE I had to ask Dickson in his office. A few months after my dad died, my mom received his autopsy report. It was written in medical language that laypersons can only puzzle through. But one passage did jump out. It said several sections of my dad's brain had lesions that resulted not from the stroke but "foreign material." I had to accept that my dad was gone, but I always wondered about that material, how it got there, and whether it was connected in any way to his death.

Dickson told me he suspected the foreign material was polymer granules that sheared off a catheter that doctors had inserted into my dad's arteries to assess the damage to his heart. As blood flowed to the brain, the polymer material "occluded" and "distended" tiny vessels in the brain, blocking blood flow and oxygen. While the initial stroke was likely caused by a blood clot due to atherosclerosis, the subsequent stroke may have been caused by the brain lesions that formed in response to the polymer material.

Your dad, Dickson said, "got the worst of both worlds. He got the stroke, and then the treatment for the stroke made it even worse."

I didn't press Dickson further on the polymer reaction because I had other questions ready for him. But later I thought a lot about it. I attained my dad's medical records and found no mention of the polymers. I told my mom. "I was shocked that no one ever told us about it," she said. "It was a piece of information I should have known, and I should have been told. I certainly would have not reacted quietly. I would have been a lot louder."

I learned, though, the doctors who treated my dad likely didn't know about the polymer leakage from the catheter. Except for a handful of medical journal articles and newspaper articles, the problem of polymers shearing from catheters into patients' blood and organs is practically unknown.

Tyler Hickey, an assistant professor of medicine and pathology at the University of Toronto, who wrote one of those journal articles, published in 2019, told me that most medical personnel are indeed unaware of the problem. During procedures, he added, they can't see the microscopic particles. "They get scattered into little areas in the brain—it's death by a thousand cuts." Hickey's study of 110 patients who had catheter treatments within 90 days of their deaths showed that polymer materials in their bodies caused death in nine of them.

Hickey was kind enough to look at my dad's autopsy report for me. "The polymer leakage certainly may have exacerbated the initial problem the physicians were trying to treat," he told me. "But it's impossible to know if your dad would have lived without the polymer material. Unfortunately, the leakage is just a quality of these catheter designs." That was cold comfort to hear.

As Dickson and I continued to talk in his office, he told me the polymer contamination in my dad's brain made it "one of a kind" among the thousands of brains in the Mayo Clinic brain bank. It was a VIP in brain research in another way. Because there was no trace of dementia in his brain, it would be used as a healthy control. Control brains are used in research

“He got the stroke, and
then the treatment
for the stroke made it
even worse.”

to measure brain changes that are related to diseases like Alzheimer’s and vascular dementia, and to better understand advancements in rehabilitation for stroke patients who have lost the ability to communicate. “We don’t get enough healthy brains to use as normal controls,” Dickson said, expressing his gratitude that my dad had donated. His brain tissue can now be checked out like a book from stacks of shelves to answer so many scientific questions.

After I said goodbye to Dickson, I waited in the Mayo Clinic lobby for my taxi to the airport. I watched a father push his elderly mother in a wheelchair while her grandson cuddled on her lap. I thought about my own aging and brain and wondered whether my dad’s love of words and story helped keep his brain strong. Studies have revealed that our most human qualities, our connections and collective stories, can protect our memories and keep our brains strong as we age. Sharing personal stories or fictional narratives can improve the neuroplasticity of the neural networks and encourage new neural connections. It can also boost neurotransmitters such as dopamine and serotonin, which enhance mood and motivation. No doubt this emerging science proves why my dad continued to excel in memory tests until the end.

Our connections and collective stories can keep our brains strong as we age.

In the taxi, I called my mom, who is 86 and still writing poetry and short stories every day, to tell her about the visit. “What he did for the world is so beautiful and magical,” I told her. “His brain is continuing, life goes on indefinitely with this research.” She became quiet. “Well, when you’re done with this, you and your brother still have to deal with the ashes. It’s not nothing. It’s a different thing.”

MY DAD’S ASHES SIT inside a bookshelf in the Riverdale home where I grew up. He was an avid fly fisherman, and his final wish was for us to spread his ashes in a trout stream where he used to fish. In the *New York Times* obituary of my dad, Robert McFadden quoted from my dad’s review of the anthology *The Habits of Rivers* edited by Ted Leeson: “The wonder of these dozens of pieces is that they offer a lesson in the art of living,” he wrote. “Or, more precisely, in the art of getting outside yourself, which is essential to sane living.”

Reading these words made me realize that this visit to his brain was a way to see the bigger picture of my dad. He saw himself as part of a larger corpus of connected stories. This approach to life was punctuated by the words of his college buddy, the novelist Norman Rush, author of *Mortals*, who spoke at his memorial.

“Chris was an engaged man, with a citizenly approach to those tasks and institutions that help sustain enlightenment, idealism, and human decency,” Rush said. “He was generous with his mortal life.” Rush named my dad’s connections to his high school board and the James Joyce Society. He mentioned my dad’s commitment to the “long-term aging study that involved detailed record-keeping and irksome visits to the doctors managing the project. This was citizen Christopher.”

Growing up, I often felt invisible to these pursuits when he worked so many hours in his home study, intensely focused on other writers' words and his own to support our family. Now that I'm older and a parent, I see this effort better; his choices to get outside of himself. He showed up. He said yes to it all. He, indeed, was generous with his mortal life. The gift of his brain to science has given me a way to see my dad as a man just trying to get through all the stresses, pains, and baggage—and the joys of enjoying good food and a little too much brandy—that we all accumulate in our bodies. Mostly, I now know that I share the DNA of his brain, and the rest of the story is unfolding through me, giving me the connection with him I had always yearned for.

In the 17th century, the philosopher René Descartes proposed that humans have a body and a soul that exist outside the body, immaterial and indestructible. He called the non-physical stuff of thinking *res cogitans* and everything else, the physical that runs through our nerves, *res extensa*. My family has not yet had the ceremony to send my dad off down the river, so this story feels, in a way, unfinished.

But if there's one thing I came to realize more deeply than ever before about my father, it's this: His words and the wisdom in them will always live in archives that can be called up with fingers, and his brain will live on in the network of brains pushing the boundaries of science, and his ashes—maybe his soul—will be part of nature, forever flowing. ☺

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Guinea Pig Toes

When evolution is cruel to be kind. How Sewall Wright tweaked Darwin.

BY ZACHARY B. HANCOCK

A

GRAY, BESPECTACLED OLD MAN, in a voice that was quiet and timid, suggested to the audience of animal breeders and geneticists that he had perhaps overworked the word *balance*. “Poise,” he proffered, might have been better—to be *poised* implies a constant readiness to shift, to make leaps.¹ That’s how evolution worked to Sewall Wright.

It was 1977, and the 88-year-old world-renowned evolutionary biologist was speaking to the assembly at the annual meeting of the American Society of Animal Science. But Wright’s daring ideas about evolution had coalesced when he was a much younger man, confronted with what he saw was a major gap in Charles Darwin’s theory of natural selection: How organisms could evolve new and better features when transitional, interim changes would make them less fit.

As an evolutionary biologist, I can’t go far in my work without tripping over an insight from Wright. But his work’s importance crystalized on the world health stage when strange new mutations of the COVID-19 virus began emerging. When, in 2022, the Omicron variant rapidly replaced the original variant due to its higher infectivity, researchers discovered that this superpower had actually resulted from a series of about nine mutations that initially *reduced* its infectiousness.² How did a virus that was initially less infectious persist

long enough to obtain the next mutations to become even more infectious than the original variant?

The first inklings of an answer to this contemporary question came to Wright more than 100 years ago, when he met a guinea pig with an unusual number of toes.

Wright had been interested in evolution since he was a teenager, having read Darwin’s *On the Origin of Species* for the first time in high school. Unlike Darwin, who admitted to being terrible at math, Wright was remarkably gifted at numerical feats. He could extract cube roots by 8 years old; when his teachers found this out on his first day of school, they paraded him in front of the eighth-grade boys, asking him to perform the trick on the chalkboard that he could barely reach. This won him few friends, and Wright afterward refrained from speaking out much in class. Wright would carry on being known as shy and reserved for much of his life.³

Nowhere does there exist a pig with wings, a bird with antlers, or a frog species with six legs.

His formal biology training was at Lombard College in Illinois under the tutelage of Wilhelmine Key, one of the first women to receive a doctorate in biology from the University of Chicago. From her, Wright discovered for the first time that evolution, statistics, and genetics were all intertwined, and that he could apply his mathematical skills to big questions in biology.

Under her insistence that Wright pursue graduate school, he went on to work in the lab of the famous geneticist William Ernest Castle at Harvard University's Bussey Institute. There he took over management of a thriving colony of guinea pigs, housed in a gothic-style mansion in Boston.⁴ In the early 1900s, guinea pigs were still the lab animal of choice, not yet replaced by mice and rats.

Wright's work with the guinea pigs would set him on a path that would ultimately lead him to depart with his contemporaries and to propose a radical new theory of evolution. Most biologists since Darwin had thought about evolution as a process of gradual improvement, natural selection acting on slight differences between individuals. But for Wright, evolution was about how organisms leap between optimal states of adaptation, crossing dangerous valleys of low fitness in the process.

THERE ARE A LOT OF WAYS to build an animal. The biodiversity of our planet is a testament to this. But if you imagine an organism as a fully constructed Lego toy, consider all the ways those individual bricks could be reassembled to build a wholly new thing. The entire range of possible assemblies is vast and yet the living world occupies only a tiny fraction of this design space. Nowhere does there exist a pig with wings, a bird with antlers, or a frog species with six legs.

One reason, first hinted at by Darwin, is that certain assemblies simply work better in their environment than others. These configurations allow organisms to

survive and reproduce, passing on their specific Lego blueprint to the next generation. Once an organism has arrived at a structure that does well in its environment, randomly swapping some pieces are more likely to cause harm than further improvement.

But what if swapping a dozen pieces in a precise way would be transformative in making that organism perform far better in their environment? But any individual swaps would result in a worse-off animal. So, how do you reach the vastly improved one? This is a kind of Darwinian paradox—changing each piece one-by-one reduces the integrity of this Lego critter, and so natural selection, the force at work here, should remove those changes, preventing the necessary dozen steps from ever being taken to reach the far better configuration just on the other side of the unfit valley. How is evolution not forever stuck in this suboptimal state? A long-running experiment provided Wright just the right small subjects to find out.

THE NAME "EXPERIMENT B"—conducted in a government lab in Beltsville, Maryland, for the now-defunct Bureau of Animal Industry—holds an aura of secrecy and intrigue. If you had visited the facilities, you would've been greeted by a dual assault on your senses: first, your nose at the sharp aroma of alfalfa hay, wood shavings, and urine, then your ears by a cacophony of shrieks, whistles, and whines.

Over the course of two decades, the experimental station housed more than 80,000 guinea pigs. The colonies were established in 1906 in response to the Bureau's mission to uncover the effects of inbreeding on the nation's livestock. Since the late 1700s, it had become common practice for farmers to tightly control the mating of their herds, permitting only those that produced a lot of milk, grew muscle rapidly, etc., to breed. In doing so, their herds became increasingly uniform. Brothers would be mated with sisters, daughters with fathers, whatever it

took to keep the optimal traits in the herd. Concerns about the negative side-effects of agricultural inbreeding practices had been mounting for decades—even Darwin himself wrote about them in his little-known book, *The Effects of Cross and Self-Fertilization in the Vegetable Kingdom*—and the United States government decided there needed to be a large-scale experiment conducted to survey the full range of health implications.

So in 1911, a few hundred guinea pigs were chosen to establish a colony with strict brother-sister mating, kicking off Experiment B. A few dozen family lines were maintained in this way, and health impacts measured every generation. Records were kept of their color patterns, litter size, and weight, and they were exposed to tuberculosis and other pathogens to test resistance. In just a few years, Experiment B had produced a massive database of information—all they needed was a skilled statistician to analyze it all.

At the time, Wright happened to be learning the ropes of guinea pig genetics up in Boston. In his care were the “BB” stock of intensely black guinea pigs, and the “BW” stock of a mix of black and albino piggies. There were tricolors with spots of yellow, rough coats and smooth coats, cream-colored ones, and the red-eyed stock. Each stock delineated by coat color, pattern, and roughness, and given labels of predicted genotypes. All of these varieties were common among guinea pig breeders and can be found at any pet store. But one of the lines stood out.

Guinea pigs belong to the family Caviidae and are characterized by having four toes on their front feet and only three toes on their back. But in 1906, Castle had discovered one of his pups was born with an extra toe on its back foot. It was a flimsy thing with no bone or muscle—just an atavistic vestige. And yet, he wondered if this extra toe could be selected to grow normally across successive generations.

The result was a unique four-toed stock now in Wright’s care. Scooping up one of these piggies, using his thumb to separate the toes, he marveled at this perfect oddity. In only a few generations of selection, here was a guinea pig with four completely normal toes on its back feet. Something no caviid was supposed to have.

How did this happen? Was it the result of one gene, two genes, 50 genes? In 1912, no one really knew what a



TEACHER’S PET Evolutionary biologist Sewall Wright kept his guinea pig study subjects close at hand (literally—he would bring them to his lectures) throughout his career; they had served as inspiration for his grand theory of evolution that helped explain what he saw as a hole in Darwin’s ideas around natural selection.

gene even was—the physical structure of DNA wouldn’t be elucidated for another four decades. The only way to investigate heredity was through carefully designed crosses and detailed statistical analysis over many generations. Not much differently than Gregor Mendel had a half-century before.

For the next three years at Harvard, Wright dedicated himself to uncovering the secrets of heredity in Castle’s guinea pigs. His most dramatic success there was not in the toe department but in working out the genetic basis of albinism. In guinea pigs, albinism isn’t an all-or-nothing trait—there’s an almost continuous gradation from intense black to white. While many people at the time thought that traits were determined



He wondered if this extra toe could be selected to grow normally across successive generations.

by just one or a few genes acting independently of each other, Wright discovered that this continuity was due to a complex gene interaction system. Some genes determined the color, while others determined how strong the color would be, with some having versions of the gene, alleles, that were dominant or recessive to other versions. He would later uncover a similar phenomenon with toe number—to shift from three to four toes required crossing a developmental threshold by possessing unique combinations of many alleles.⁴

This would be the first important lesson that guinea pigs would teach Wright: Nothing in biology is simple. Even seemingly simple traits such as “color” are determined by an exquisitely complex system.

Wright graduated with his Ph.D. from Harvard in 1915, and, under the recommendation of Castle, accepted a position at the Bureau of Animal Industry to analyze the abundant data that had accumulated from Experiment B and to help guide the guinea pig breeding program there.² The guinea pig stock was much different than it was at the Bussey, however, which had bred for diversity of stock. All the family lines were genetically homogenous just like highly inbred cattle.

But there was something curious about these lines in Maryland. There were 23 family lines, all descendants of the same breed of guinea pig, and all inbred. And yet, each line was remarkably different from the other. One line had very short legs that made them look as if they were gliding across the ground. Another was almost entirely white, while another only had a smear of white on the snout. Some had little rounded noses with bent ears, while others had pointy noses with erect ears. It appeared to Wright that there was more variation between each of these inbred lines than there was in the original breed.¹

He realized that by isolating each family line from the other, it revealed a kind of hidden reservoir of



THIS LITTLE PIGGIE

In the 1910s, Sewall Wright met a guinea pig with an unusual number of toes. It showed him that evolution's progress is rarely as straightforward as many scientists of the time thought.

variation. In large populations, certain combinations of genes, especially if alleles are at very low frequency, are highly unlikely to occur. But in small, isolated populations, the probability of rare gene combinations increases substantially. In the Lego building blocks analogy, say a box has a dozen or so colors of blocks, but the red block is by far the most common. If you draw from this large box randomly, you'll almost always get a creature made of red blocks. However, if you pour the blocks from this large box into many smaller tubs, by chance, some of the rarer colors will be overrepresented in one or more of these smaller tubs. Now, by drawing blocks from each isolated tub separately, you increase the chance of pairing blocks of many different colors other than the dominant red one. If each generation these Lego creatures are constructed by a limited number of draws from each tub, then, over time, the proportion of colors will change in each tub by chance.

In this way, each small, isolated guinea pig family line appeared to have moved through the adaptive landscape by dumb luck of the Lego brick pour—or genetic drift—in its own unique trajectory, and it did so rapidly because the pens held only a few individuals.

At the Bureau, Wright also had access to centuries worth of livestock records, including detailed pedigrees. In studying the history of the shorthorn bull, he learned that most all of the prized bulls descended from a single cow named Favourite. Her descendants with their desirable traits were then shipped to other herds all over the country, no doubt fetching high prices, to infuse the local herds with their genes. At least to the farmer, this led, ultimately, to the improvement of the entire shorthorn breed.¹

Wright realized something that, in retrospect, seems obvious, but had never been applied to evolutionary thinking before. Farmers have their own isolated herds each experiencing drift in their own unique directions until one of them stumbles upon a highly desired trait—like that found in Favourite and her offspring. Only then do farmers select for those prized traits to percolate through the rest of the stock, rapidly reshaping the breed as a whole. In evolutionary terminology, the shipping around of animals between herds is the gene flow. In nature, it happens when occasionally organisms migrate between otherwise isolated populations, bringing with them their unique gene combinations.

Nothing in biology is simple.

By the time Wright was offered a professorship at the University of Chicago in 1925, all these ideas had begun to coalesce in his mind—the gene interaction systems of coat color, hidden reservoirs revealed by isolation, and the shipping of new traits between isolated populations.² While all these things were artificial, driven by the whims of human breeders, Wright wondered if there wasn't a parallel of this in nature. After all, Darwin had been inspired by how breeders “artificially selected” traits, which ultimately led him to conclude nature could do the same thing.

ALL THE PIECES are on the table, scattered and disorganized, disconnected observations from the career of one man. Now at the University of Chicago, guinea pigs in tow from Maryland, Wright sat down to flesh out his own theory of evolution. It first appeared in 1931 in a landmark paper titled “Evolution in Mendelian Populations.”⁵ In it, he imagined all collections of various advantageous traits like peaks on a rugged landscape separated by treacherous, less-fit valleys. In his “adaptive landscape” metaphor, some summits were higher than others, and there was, somewhere in this landscape, the tallest mountain—the optimal fitness peak.

Perhaps a population of guinea pigs has been stranded on a suboptimal peak of fitness, having a mere three toes on each rear paw when four might be optimal. They can get by well enough, but their adaptations are not the optimal combination. Wright asks us to imagine, however, that instead of one big population, we in fact

have lots of small, isolated ones—our guinea pigs are in separate pens, or, in their natural environment, scattered across the Andes, rarely in contact. This is the state of most organisms, which are limited in how far they can travel in their lifetime. Even really big populations, such as mosquitoes or fruit flies, experience some degree of localized inbreeding. Not to the same extreme as the captive guinea pigs, but enough that it might expose hidden variation.

Because these local populations are fairly small, chance starts to play a larger role in their gene frequencies. These populations diverge from each other, just like the guinea pig lines in Experiment B. So long as the novel combinations aren't *too* harmful, genetic drift allows local populations to slip off the peaks of fitness, acting counter to natural selection. This temporarily reduces fitness in the isolated population, but it opens the door to exploring neighboring peaks, which might offer far higher fitness—they've made the dozen swaps and reached the top of the ideal mountain of four toes. But now only this population of guinea pigs has arrived—the rest are still scattered throughout the landscape in the suboptimal three-toed state.

But migrant guinea pigs, with their superior four toes, travel to other populations, like prized shorthorn bulls being shipped to other herds, seeding within local populations their winning combination features. Evolution has escaped the suboptimal state.

This was Wright's wild insight, which he called the shifting-balance theory of evolution.

THE NAME “SEWALL WRIGHT” haunts the bibliography section of every scientific paper I’ve ever written. Indeed, he became one of the most prolific and influential biologists of the 20th century. But most biologists engage with his ideas in isolated fashion. A conservation biologist might use his “F-statistics,” which measure the amount of inbreeding an endangered species is experiencing. Wildlife biologists studying animal dispersal rely on many of Wright’s mathematical models of gene flow. Laboratory biologists have used Wright’s work to understand the influence of genetic drift on their test-tube organisms.

But Wright’s contributions to each of these topics were not formulated in isolation. To him, each piece was a component of his overarching theory of evolution. To get there, he had needed to draw from the interactions between complex genetic systems, natural selection, genetic drift, gene flow, and mutation. By integrating all these factors of evolution, he developed a holistic theory that, to him, explained the great mystery of how organisms can reach new peaks of fitness.

The legacy of his shifting-balance theory is currently a contentious one among us population geneticists. Some researchers have argued that it lacks broad empirical support and is overly complex⁶; others contend its strength lies in this complexity, and that its support is growing.^{7, 8} To return to the Omicron variant, one hypothesis proposed for the “valley crossing” was that the virus was evolving in an immunocompromised individual, therefore weakening selection by the immune system against the virus, allowing genetic drift and mutation to pull the viral population within the infected host through a fitness valley.⁹ Once the new fitness peak of high infectivity was realized, it then rapidly spread from the host to other healthy individuals, eventually replacing the previous variant.

But the lesson I take away from Wright is that evolution doesn’t need to proceed methodically, one step at a time, always uphill, solely by the action of natural selection. Sometimes, it stumbles down the cliff. Others, it leaps to the top. And occasionally, it takes random walks through the landscape of mutations. As Wright once remarked, species are poised for all kinds of change. The paths of big ideas themselves often aren’t that different.

Wright’s love for guinea pigs persisted throughout his life, and he reveled in the opportunity to smuggle a

piggie into a lecture hall. He was not a terribly engaging speaker, and most of his students remember him as a kind of absent-minded genius. One day, the story goes, Wright tucked a particularly squirmy guinea pig under his arm where he often held his eraser as he scrawled equations onto the blackboard. Having made an arithmetic error, he reached for his eraser.

Guinea pigs, it turns out, have uses beyond teaching us about evolution. ☺

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How To Tell If You're Dead

The line between life and death has never been clear—and modern technology blurs it further

BY AMANDA HEIDT

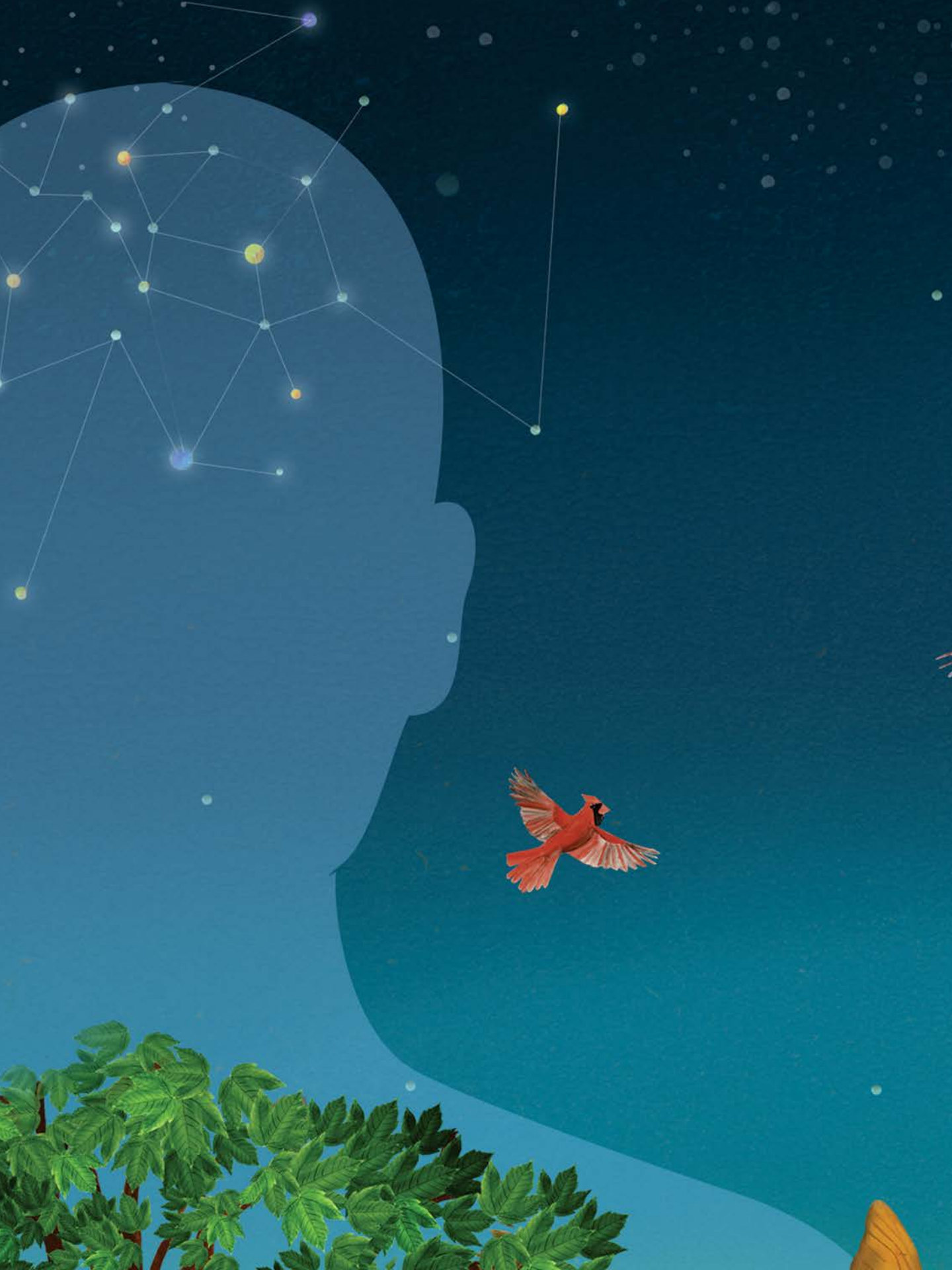
JIMO BORJIGIN NEVER INTENDED to study death. Back in the mid-2010s, the consciousness researcher at the University of Michigan Medical School in Ann Arbor was instead interested in circadian rhythms, the internal cycles that regulate our physical, mental, and behavioral states throughout each day. The circadian clock is a bit of a black box, Borjigin says, so to study it she and her team developed an automated system to continuously monitor neurotransmitters that regulate circadian rhythms in rats.

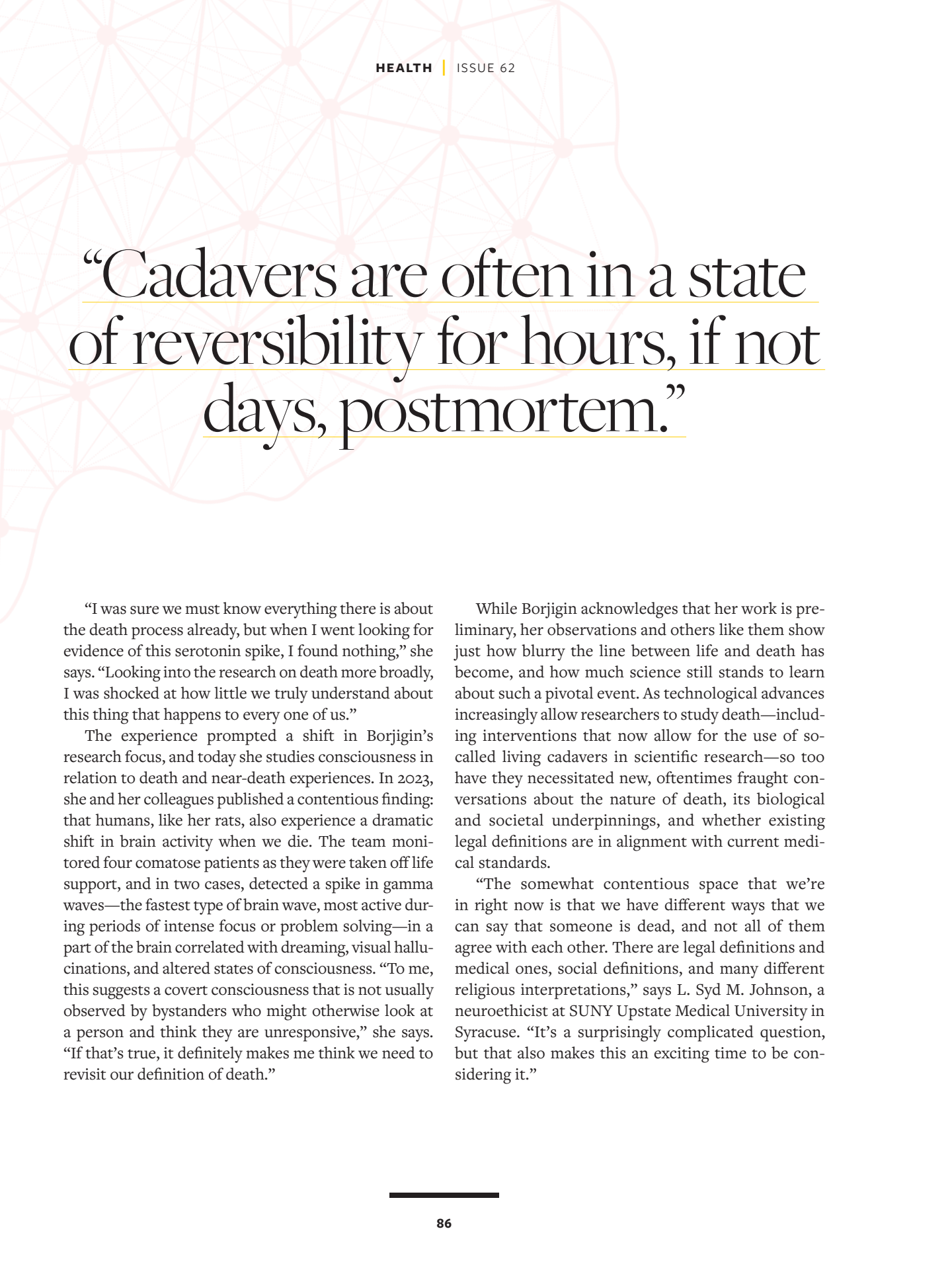
Over the course of her research, the scientists tracked the animals for weeks at a time, and Borjigin began to notice something unusual. A few of the animals died while under observation, and when they did, the researchers' sensors recorded a massive and unexpected spike in serotonin for up to 30 seconds after their hearts stopped beating. In humans, serotonin dysregulation has been linked to intense hallucinations, but Borjigin didn't know what to make of such a finding in the context of rats. Or in death. Like any good scientist, she looked to the literature.



ILLUSTRATION BY ELLEN WEINSTEIN







“Cadavers are often in a state of reversibility for hours, if not days, postmortem.”

“I was sure we must know everything there is about the death process already, but when I went looking for evidence of this serotonin spike, I found nothing,” she says. “Looking into the research on death more broadly, I was shocked at how little we truly understand about this thing that happens to every one of us.”

The experience prompted a shift in Borjigin’s research focus, and today she studies consciousness in relation to death and near-death experiences. In 2023, she and her colleagues published a contentious finding: that humans, like her rats, also experience a dramatic shift in brain activity when we die. The team monitored four comatose patients as they were taken off life support, and in two cases, detected a spike in gamma waves—the fastest type of brain wave, most active during periods of intense focus or problem solving—in a part of the brain correlated with dreaming, visual hallucinations, and altered states of consciousness. “To me, this suggests a covert consciousness that is not usually observed by bystanders who might otherwise look at a person and think they are unresponsive,” she says. “If that’s true, it definitely makes me think we need to revisit our definition of death.”

While Borjigin acknowledges that her work is preliminary, her observations and others like them show just how blurry the line between life and death has become, and how much science still stands to learn about such a pivotal event. As technological advances increasingly allow researchers to study death—including interventions that now allow for the use of so-called living cadavers in scientific research—so too have they necessitated new, oftentimes fraught conversations about the nature of death, its biological and societal underpinnings, and whether existing legal definitions are in alignment with current medical standards.

“The somewhat contentious space that we’re in right now is that we have different ways that we can say that someone is dead, and not all of them agree with each other. There are legal definitions and medical ones, social definitions, and many different religious interpretations,” says L. Syd M. Johnson, a neuroethicist at SUNY Upstate Medical University in Syracuse. “It’s a surprisingly complicated question, but that also makes this an exciting time to be considering it.”

ACROSS MANY CULTURES, life has been linked not to our bodies, but to intangible souls, and so questions of death remained most squarely in the purview of religious representatives. Early definitions associated with Western religions in the mid 1700s timestamped death using the soul's departure from the body. It wasn't until about a century later that the first biological description of death—the cessation of heart action and breathing—appeared in a medical text, 1873's *Manual of Medical Jurisprudence*, written by Alfred Swaine Taylor, a British toxicologist and medical writer. This so-called cardiopulmonary concept dominated scientific thinking for the next century, and remains the most common criteria by which doctors declare someone dead today.

But medical advances, including interventions such as CPR and organ transplantation and the emergence of technologies including ventilators and defibrillators, have increasingly clouded that definition. People who might once have died from drowning or heart failure can now be resuscitated, receive an organ transplant, or even have their circulation artificially maintained. Death, many scientists now argue, is better thought of not as an absolute, but as a complex and evolving process that can sometimes be reversed with proper care.

"Irreversibility is just a reflection of a lack of medical treatments, which we're developing more of all the time," says Sam Parnia, a clinician at NYU Langone Medical Center in New York City who focuses on cardiac arrest. "We see now that death is a continuum, and cadavers are often in a state of reversibility for hours, if not days postmortem."

The emergence of neuroscience as a discipline prompted even more rethinking on death. In 1968, a committee based at Harvard University met to establish a definition centered around neurological criteria. In their final report, the group described death, in part, as an "irreversible coma," a term they used somewhat interchangeably with what we would today refer to as brain death.

Not everyone agreed with this approach, with one researcher calling the recommendations "a bane for bioethicists from day one." At the time, the question of when to stop providing life support was not clearly differentiated from the question of when a patient was dead, and the group's chair, Harvard anesthesiologist Henry Beecher, referenced a hypothetical future in

which "hopelessly unconscious" patients would take up space in hospitals at enormous cost. Others were hesitant to declare death too soon, however, worried that premature declarations could be rushed to kickstart the harvesting of organs for donation.

Some of this contention was settled with the passing of the Uniform Determination of Death Act (UDDA) in 1981, a model United States law intended to help states craft their own unified policies. The UDDA sought to bridge the cardiopulmonary and brain-based concepts, defining death as *either* the irreversible cessation of circulatory and respiratory functions *or* the irreversible cessation of all functions of the entire brain, including the brain stem. This latter point acknowledges that it's the brainstem that controls essential, automatic functions such as breathing, heart rate, and blood pressure, and its inclusion places the UDDA more in line with a "whole-brain" approach rather than a "higher brain" model focusing on consciousness as a hallmark of life. Today, medical professions use UDDA criteria when declaring someone dead, kickstarting the legal, social, and clinical processes that come next, including organ donation, mourning rituals, and the settling of a person's personal affairs.

The UDDA has generally been successful in its purpose for the past 40 years, says David Magnus, the director of the Stanford Center for Biomedical Ethics in California, even though it too has garnered its share of controversy. "The UDDA is an amazingly successful policy—tens of millions of people die each year, and we're generally not arguing over that because of the criteria we have," he says. "Having said that, a feeling has grown over time that there's a lack of fit between the actual language of the law and the details of clinical practice, such that we're now reconsidering our definitions once again."

MANY OF THE ARGUMENTS around how we define death stem from a lack of consensus over what tests or metrics should be used to verify that death has occurred, and how much philosophy should factor into medical or legal decisions.

For example, since the passing of the UDDA, researchers have found that the hypothalamus—a brain region that regulates appetite, sleep, and hormone release—often continues to function for longer



The meaning of death— perhaps the most personal experience there is—should be left to each of us to decide.

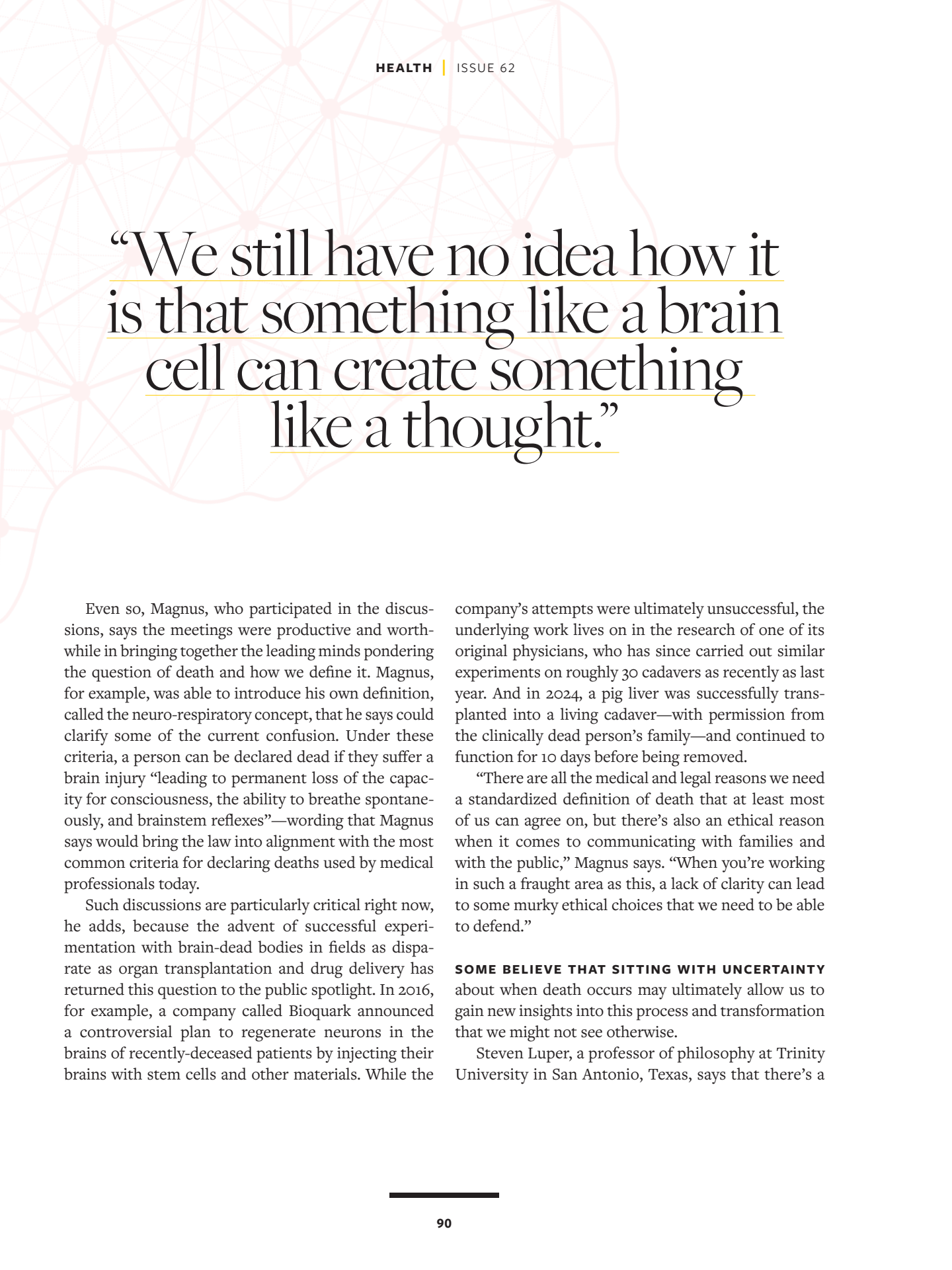
than the rest of the brain after death. This prolonged hypothalamic activity results from that region receiving some blood flow from a different source than the rest of the brain. While most blood flow makes its way to the brain from the carotid arteries in the neck, the hypothalamus is also supplied via a network of arteries at the base of the brain called the circle of Willis. Medical professionals largely agree that a functioning hypothalamus isn't a meaningful sign of life, but some physicians have suggested that an additional test for this should be added to the criteria for declaring death. Doing so would necessitate rewriting the UDDA, however, and its reference to a cessation of function across the entire brain.

Piotr Nowak, a bioethicist at Jagiellonian University in Kraków, Poland, notes that there are also several cases over the past few decades that show how ambiguities in laws about determining clinical death can create confusion. Many questions involve considerations of consciousness—a more philosophical aspect that does not come, yet, with its own set of medical tests.

Among the most famous of these cases involves Jahi McMath, a California teenager who was declared brain-dead in 2013 at the age of 13 following complications from a tonsillectomy. Her family resisted the

declaration, and McMath was kept on life support for another four years, continuing to develop, undergoing puberty, and appearing to demonstrate some responsive behaviors, such as small movements and sporadic changes in her heart rate, before dying from liver failure in 2018. McMath's story echoes others in which people have regained consciousness following long periods of brain death, alongside animal studies showing that at least some brain function can be restored in pigs hours after death. "It's clear our understanding of our own mind remains incomplete in ways that make medical and policy choices difficult," Nowak says.

In response to the changing medical landscape, including clinical innovations and what they have revealed about the human brain, bioethicists, medical professionals, lawyers, representatives from advocacy groups, and others have been coming together to rethink what brain death actually means. One group, called the World Brain Death Project, has been working to establish an international framework for brain death, while in the U.S., a group met in 2021 to gauge whether an update to the UDDA might now be needed. The group agreed on the necessity of an update but failed to reach a universal agreement, and today, the law remains as originally written.



“We still have no idea how it is that something like a brain cell can create something like a thought.”

Even so, Magnus, who participated in the discussions, says the meetings were productive and worthwhile in bringing together the leading minds pondering the question of death and how we define it. Magnus, for example, was able to introduce his own definition, called the neuro-respiratory concept, that he says could clarify some of the current confusion. Under these criteria, a person can be declared dead if they suffer a brain injury “leading to permanent loss of the capacity for consciousness, the ability to breathe spontaneously, and brainstem reflexes”—wording that Magnus says would bring the law into alignment with the most common criteria for declaring deaths used by medical professionals today.

Such discussions are particularly critical right now, he adds, because the advent of successful experimentation with brain-dead bodies in fields as disparate as organ transplantation and drug delivery has returned this question to the public spotlight. In 2016, for example, a company called Bioquark announced a controversial plan to regenerate neurons in the brains of recently-deceased patients by injecting their brains with stem cells and other materials. While the

company’s attempts were ultimately unsuccessful, the underlying work lives on in the research of one of its original physicians, who has since carried out similar experiments on roughly 30 cadavers as recently as last year. And in 2024, a pig liver was successfully transplanted into a living cadaver—with permission from the clinically dead person’s family—and continued to function for 10 days before being removed.

“There are all the medical and legal reasons we need a standardized definition of death that at least most of us can agree on, but there’s also an ethical reason when it comes to communicating with families and with the public,” Magnus says. “When you’re working in such a fraught area as this, a lack of clarity can lead to some murky ethical choices that we need to be able to defend.”

SOME BELIEVE THAT SITTING WITH UNCERTAINTY about when death occurs may ultimately allow us to gain new insights into this process and transformation that we might not see otherwise.

Steven Luper, a professor of philosophy at Trinity University in San Antonio, Texas, says that there’s a

growing sentiment that the moment of death—perhaps the most personal experience there is—should be left to each of us to decide and communicate through a family member, religious figure, or end of life doula. “The goal for uniform criteria is to really help out the medical profession and the law, and some people have said that’s not a good enough reason to deprive people of their liberty,” he says. “Rather, some believe we should allow each person to define their own interpretation based on their personal narratives and world views.”

Researchers are also increasingly interested in bringing a scientific perspective to debates long considered the realm of philosophy, particularly around the idea of consciousness, which is inextricably linked to questions of life, identity, and death. One barrier to this type of research is the lack of reliable metrics for studying consciousness. In fact, Parnia notes that today, there is no definitive evidence that consciousness even emerges from the brain. “We still have no idea how it is that something like a brain cell can create something like a thought,” he says.

In a large, multicenter study published in 2023, Parnia and his colleagues analyzed patterns of brain activity—including delta, theta, and alpha waves, which together dictate brain activity and various states of arousal—in patients experiencing cardiac arrest, which Parnia says is biologically “indistinguishable from death.” The results suggest that consciousness and awareness may occur as long as an hour after a person’s heart has stopped beating. Furthermore, the brain wave patterns the team detected using electroencephalography (EEG) may be the first reliable biomarkers capable of measuring consciousness over time.

Charlotte Martial, a neuroscientist in the Coma Science Group at the University of Liège in Belgium, is similarly interested in what we can learn about death from studying moments when people are potentially conscious but largely unresponsive, such as when they are under general anesthesia or experiencing cardiac arrest. These types of experiences, she says, can function as a sort of proxy for studying the moments surrounding death under laboratory conditions, rather than relying on isolated case studies with small numbers of patients. Currently, Martial is probing whether psychedelic experiences can fulfill this role, too, by

inducing states similar to near-death experiences that patients can then share details about with scientists.

“Medicine has defined these criteria for brain death, but we don’t yet understand everything about the subjective experience of that,” she says, adding that developing empirical methods for studying something like a near-death experience could help scientists better understand the distinctions between consciousness and responsiveness, and what that means for our clinical concepts of death.

Borjigin’s early discoveries about the potentially altered states in her lab rats’ brains during death continue to inspire her search for understanding. One of her working hypotheses suggests that perhaps the brain takes a more active role in how death progresses than we give it credit for. But furthering her research won’t be easy. Borjigin and others continue to face a scarcity of funding and a lot of misconceptions about the nature and purpose of their research. Death remains a contentious and hard-to-define process.

Still, understanding what happens to each of us in our final moments, crossing the borderlands between life and death, would seem a worthy inquiry. “Even as we’re still trying to wrap our own heads around it,” Borjigin says, “it seems undeniable to me that something worth looking at is going on here. ☺

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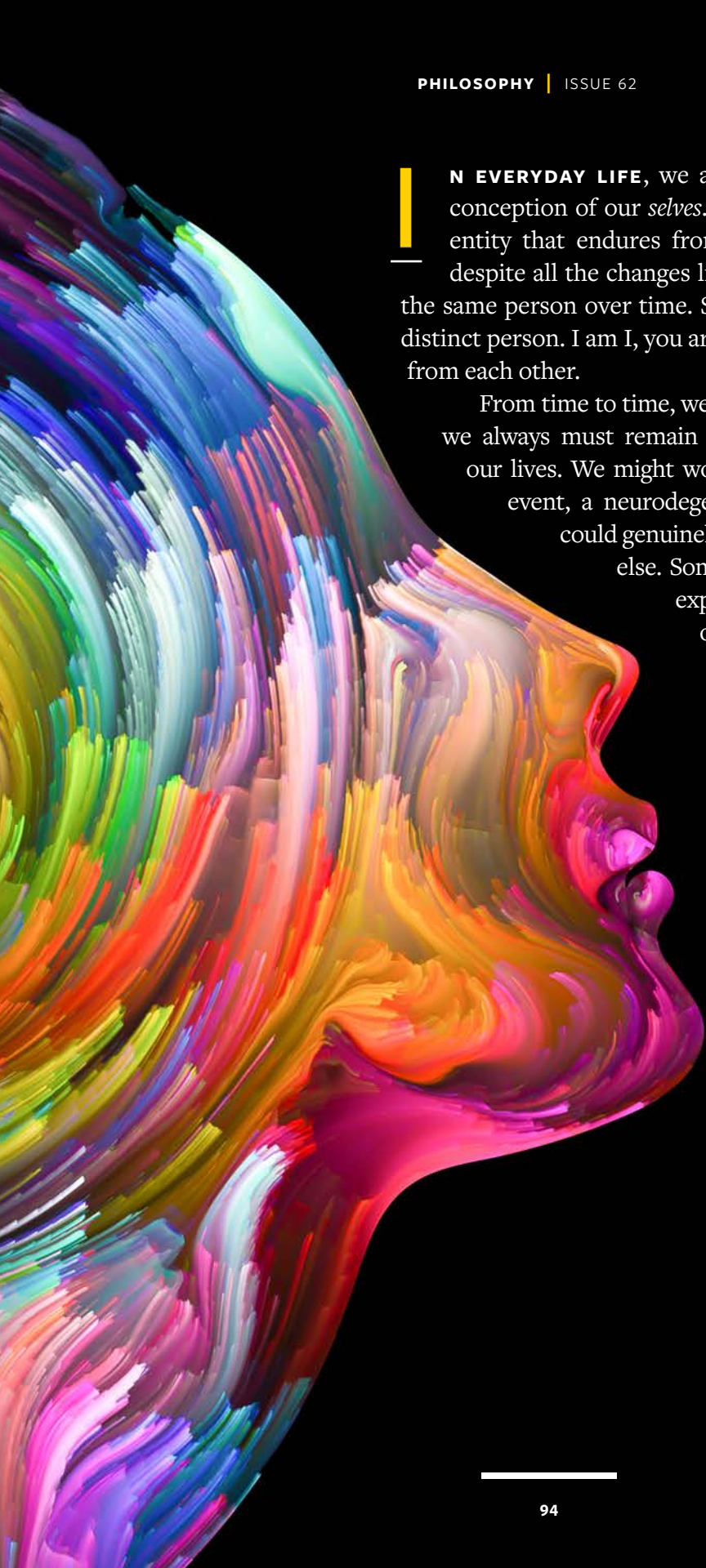
Is Everyone the Same Person?

The only way to make sense of our self is to expand it

BY HEDDA HASSEL MØRCH







IN EVERYDAY LIFE, we all take for granted a certain conception of our *selves*. I think of myself, first, as an entity that endures from one moment to the next; despite all the changes life inevitably brings, I remain the same person over time. Second, I think of myself as a distinct person. I am I, you are you, and we are all different from each other.

From time to time, we might still reflect on whether we always must remain the same person throughout our lives. We might wonder whether a dramatic life event, a neurodegenerative disease, or amnesia could genuinely turn someone into someone else. Some of us might also have been exposed to the Buddhist doctrine of *anatta* or no self, according to which there is fundamentally no self or personhood at all.

The view we are “all one” seems most often reported after a psychedelic trip.

In philosophy, as well as science fiction, we also encounter scenarios such as the *Star Trek* teleporter, or someone splitting into multiple copies, in which it is highly unclear whether, or as which one, the original person survives, leading some to question whether our sense of identity corresponds to anything real. The suspicion can be deepened by evolutionary psychology and neuroscience, in which our concept of the self is often theorized as a mere construct, selected for by evolution for its survival value rather than reflection of reality.

But to question whether we are all distinct persons occurs to far fewer of us. If it does, the possibility may strike us altogether incoherent. After all, our thoughts and experiences are clearly distinct—we cannot directly access the contents of each other’s minds in the same way we access our own. There is no telepathy or mind-reading. What could it even mean to say we are all one person when we undeniably have separate minds?

Yet, the idea appears across philosophical traditions. Arthur Schopenhauer, a 19th-century German philosopher, claimed we are all manifestations of the same underlying phenomenon, somehow seeking to experience itself as separate individuals. He was long preceded, though, by a similar view recurring in the Hinduistic Vedas: that our *true selves* (*Atman*) are all the same and identical to a single universal consciousness (*Brahman*, in turn identified with God). In other words, whereas Buddhism sees the self as an illusion, Hinduism declares it permanent and immortal, although we still suffer an illusion by conceiving of it as individual.

For a real understanding of how this could be true, however, the Hindu texts largely point toward meditation and spiritual practice, because the doctrine of a shared, universal self is considered not truly graspable by rational thought. Schopenhauer does not fully resolve its paradoxes, either. In today’s West, the view that we are somehow “all one” seems most often reported as a realization following a psychedelic trip, incommunicable to those who haven’t shared a similar experience.

Must the idea remain mystical? Perhaps not—or at least much less than one might think. In recent decades, a few philosophers within the contemporary Western tradition have looked at it with new eyes. According to their arguments, the view that everyone is the same person is not only perfectly coherent, but also quite plausible.



THE INDIVIDUAL SELF VIEW

Let's lay out the possibilities. If we are not all the same person (the shared self view) we are either different persons (the individual self view) or not really persons at all, at least not in any enduring sense (the no self view). I'm here using "person" as a synonym for "self" or "the I," whatever its nature may be; it does not imply any special psychological capacities or social roles.

According to the individual self view, every human or other conscious being is a unique enduring person. But what could it be that makes me, or anyone else, the same person over time—today, tomorrow, in 10 years, as well as yesterday and presumably back to the day I was born—while still separating me from everyone else?

The traditional answer is to invoke something like a soul, some mental thing that has my experiences, thinks my thoughts, and remains the same even as these experiences and thoughts change. But as the Enlightenment philosopher David Hume pointed out, no such soul or subject seems to be observed introspectively. Turning our gaze inward, we only observe our thoughts and experiences, flowing by in an ever-shifting stream, but no unchanging thing that has them.

What if we rather think of the self as a physical entity, such as the brain or body? This just raises the question of what makes something the same brain or body over time. Most cells in our body are continually replaced, and for those that aren't, such as neurons, their underlying biomolecular constituents still are. In the teletransporter scenario, in which your body is destroyed on Earth but an exact copy instantly assembled somewhere else, many of us can also imagine remaining the same person even if all our physical constituents are replaced at once. Or consider uploading our minds on a digital computer or replacing one's biological neurons one by one with silicon ones. If we think we could survive—that is, *you* would go on existing—in these cases, it shows that we don't really consider any of our physical features essential to ourselves.

Another option is to identify ourselves with a mental or psychological process—a series of thoughts and experiences connected in the right way. John Locke, another Enlightenment philosopher, held that to exist in the future simply means that there will exist someone with memories of your current experiences and actions. According to other thinkers, the continued existence of your self might also depend on further connections, such as being influenced by your current goals, intentions, and aspirations, or having a similar personality.

But we can imagine remaining the same person even if such psychological connections are broken. Would we really consider even complete amnesia, in which most if not all of them are lost, equivalent to dying? Imagine that you were about to take a pill that would wipe all your memories, as well as reset your goals and personality. Afterward, you would go through painful surgery without anesthesia (this example is adapted from the philosopher Roderick Chisholm). In this scenario, most of us would be worried not just

Egoism would be not only morally unjustified but altogether irrational.

about the impending memory and personality loss, but also the pain to be experienced. And not just in the altruistic way that one might worry about any person experiencing pain, but in a self-interested way: You would fear that *you* would be in pain, not just lament that *someone* will.

Another problem facing the individual self view is that most features or connections that may seem unique to us, whether psychological or physical, can be shared between what we would consider different persons. Our DNA, for example, remains constant throughout our lives, but it is also shared between identical twins without making them the same person.

More generally, imagine an entire human being dividing in two “like an amoeba,” as the philosopher Derek Parfit put it, and then regrowing the missing half. Or consider split-brain cases, in which patients have had their corpus callosum, which connects the left and right brain hemispheres, severed. (It’s controversial whether this leads to a splitting of consciousness, but suppose it does.)

What happens to the original person who existed before the split? Do they continue as just one of the halves? That seems arbitrary. Will they die and be replaced by two new ones? That seems implausible, because if after the split only one half survived, we would not hesitate to judge that the original person continues as that one. So why should the original person stop existing just because the other half also survives? The final option is that the person continues as both. But each new half would have an entirely separate consciousness. The person would be in two places at once.

All of a sudden, we are approaching the shared self view. If the same person can be in two places, what stops them from being everywhere—or in all conscious beings—at once? But if we assume, as most philosophers do, that the self cannot be shared, its basis appears to elude us. There is no feature or relation to be found, be it physical or mental, that always characterizes or connects what we may consider an individual person and never anything else.



THE NO SELF VIEW

The next possibility is that the self simply doesn't exist. That is, we may feel like we remain the same person over time—perhaps for evolutionary reasons—but we actually don't. This is the no self view.

Given this view, there may be future beings continuous with you. They may resemble you physically and mentally, or be influenced by your current goals and intentions, but they would not strictly be identical with you.

This has radical implications. Most strikingly, it completely undermines egoism. If there is no *you* in the future, there is simply nothing to be egoistic on behalf of. A future being merely continuous with you may evoke your altruism much more strongly than others, much as you pay more attention to your family and friends than to strangers, but that is a fundamentally different type of concern from the egoistic one.

At first, one might think of this as great news. If there is no enduring self or ego, egoism is not only morally unjustified but altogether irrational. If we can fully appreciate this insight on a psychological level, we should think the world would be a much better place. The insight might also liberate us from our petty self-concerns that mainly cause us worry and suffering. Claims like this can be recognized from the teachings of Buddhism.

But the no self view could also inspire a more nihilistic outlook. Rather than increasing one's concern for everyone, it might decrease one's concern for one's self. That is, it could simply make us stop caring about our own future because it will not really be ours. Indeed, given this view, none of us would have any future at all—we exist simply in this isolated moment, only to instantly die and be replaced.

These or other difficult consequences of the no self view are not reasons to reject it—a view can be correct even if we deeply wish it weren't. At the same time, we are not forced to accept it—since even if we cannot identify a basis for an individual self, that is not the only kind of self there could be.

THE SHARED SELF VIEW

What could it even mean that we are all one person? In the short story by Andy Weir, “The Egg,” a 48-year-old man dies, but wakes up in an afterlife where he is greeted by a mysterious being. The being tells him he has been reincarnated many times before, and will proceed to be reincarnated again, until he has lived the lives of every human being.

Unlike how we typically think of reincarnation, in this story, one is not restricted to being reincarnated as someone born after one’s death—the man is reincarnated as all of the people he co-existed with during his own lifetime, including his own family and friends. The shared self view posits something very similar, but with one extra twist—the man is *already* incarnated as everyone. That is, according to the shared self view, the same person lives through every life at *once* rather than one after the other.

At first blush, this view is completely at odds with what we observe. If you are the same person as everyone else, then everyone’s experiences are your experiences. Shouldn’t you then be aware of all these experiences, like a security guard watching a dozen different camera feeds at once?

But even if you need to be aware of all your experiences, you don’t need to be aware of them all at once. Consider your past experiences. You were of course aware of these experiences as they were happening, but at present, you are at best indirectly aware of them via memory. Other past experiences you have no memory of, such as early childhood experiences or unremarkable everyday events. Or consider dreams. Every night, most people have elaborate dreams that upon waking are completely forgotten, and while having them we also forget everything about our waking lives.

The shared self view can be understood as saying that the experiences of every conscious being are yours, not in the way your current experience is yours, but in the way your *past* experiences are yours; more specifically, your completely unremembered past experiences, such as your forgotten dreams.

One might object that this sort of disconnect or mutual unawareness can only hold between the same person’s experiences at different times, not at the same time. So it doesn’t explain how we are all having separate experiences right now. But all these experiences still occur in different places, such as in different human beings or brains. If the same person can have disconnected, mutually unaware experiences at different times, perhaps they can also be had in different places?

These points have been made, in various ways, by contemporary defenders of a shared self, such as Arnold Zuboff, Daniel Kolak, and Bernardo Kastrup. They show how it is at least coherent that we are all the same person. But is there any reason to think it might be true, in the absence of a mysterious being telling us so, as in Weir’s short story, or some other mystical revelation?

To defend an individual self, one would have to identify some feature—either physical or mental—that is always present throughout a human lifespan, but cannot also be shared with other individuals. To



A vertical abstract artwork on the left side of the page, featuring vibrant, swirling colors like purple, blue, green, yellow, and orange, creating a sense of motion and depth.

A welcome consequence of the shared self view is you get eternal life.

support the existence of a shared self, we instead need to look for something that all humans invariably do share.

As Zuboff argues—echoing both Schopenhauer and the Vedas—there is a clear candidate for such a feature. At any point of your existence, you will be having a conscious experience (or at least the potential for it, as in deep sleep as opposed to death). All your conscious experiences are such that you have to be directly aware of them (at least at the time, and place, they are occurring). That is, your experiences always have a subjective presence, a kind of luminosity with which they shine and appear right before you.

But this kind of subjective presence is surely not unique to those experiences you ordinarily consider yours. If other beings have experiences at all, they must be subjectively present in exactly the same way. If subjective presence is what makes an experience yours, it follows that every experience is yours, and that you are therefore everyone. As Zuboff puts it, every experience comes with a sense of being “for me,” and rather than separating us, this is what unites us.

One might object that your experiences are not merely subjectively present, but subjectively present to *you*, whereas mine are subjectively present to me. Subjective presence is therefore not the very same phenomenon in each of us.

But what is this *you* that your experiences are present before? As shown by the problems of the individual self, it can't be associated with any specific psychological or physical features, as you can imagine remaining the same even if almost everything about you changed. If anything, then, this *you* seems like nothing more than a pure point of view, with no discernible further properties. Unlike a soul—of the sort dismissed by Hume—this point seems built into experiences themselves; it is not an entity separate and independent from them, and it has no unique features or identity.

The insight that you, insofar as you can know or observe yourself, are really nothing more than a witnessing, featureless point, is frequently reported as revealed in meditation, but it also seems noticeable just from ordinary introspection. It follows that even if the experiences of others are present to a point of view, that would not make them any different from your experiences, because their points of view would be exactly indistinguishable from yours. According to the shared self view, moreover, these points of view are not merely indistinguishable but the very same, in the same way we typically think our own past, present, and future points of view are.

In this way, the shared self view can be seen to rest on observation and analysis of our own subjective experience—the ordinary, non-mystical experience that everyone has. It is also compatible with modern science. Modern science poses severe challenges to the individual self by finding no indications of an immaterial soul. It also offers explanations of how we can feel like sharply divided individuals without this actually being so. But modern science does not debunk the existence of consciousness, nor the fundamental sameness of its inherent quality of subjective presence.

Like the no self view, the consequences of a shared self can be viewed as both good and bad. Unlike the no self view, a shared self clearly supports altruism or a sense of universal compassion, rather than nihilism, as the alternative to egoism. If we are all fundamentally the same person, the only rational thing would be to care about the experiences of every conscious being as though they are your own, because that is what they actually will be. Similarly, you yourself will directly experience every consequence of your own actions. It is hard to imagine a stronger argument for compassionate, moral behavior.

As another welcome consequence you also get eternal life, or at least something very close: As long as there are any conscious beings around, with subjectively present experiences, you will continue to exist.

The flipside is that you will also experience more suffering than you could ever imagine, since every experience is yours, including the most absolutely horrifying. It can also induce a sense of deep cosmic loneliness, as fundamentally speaking, there is nobody around but you.

But as before, difficult implications are not enough to make a view implausible. It just means we—you, I, *Atman*, consciousness, everything—need to figure out how to live with it. ☺

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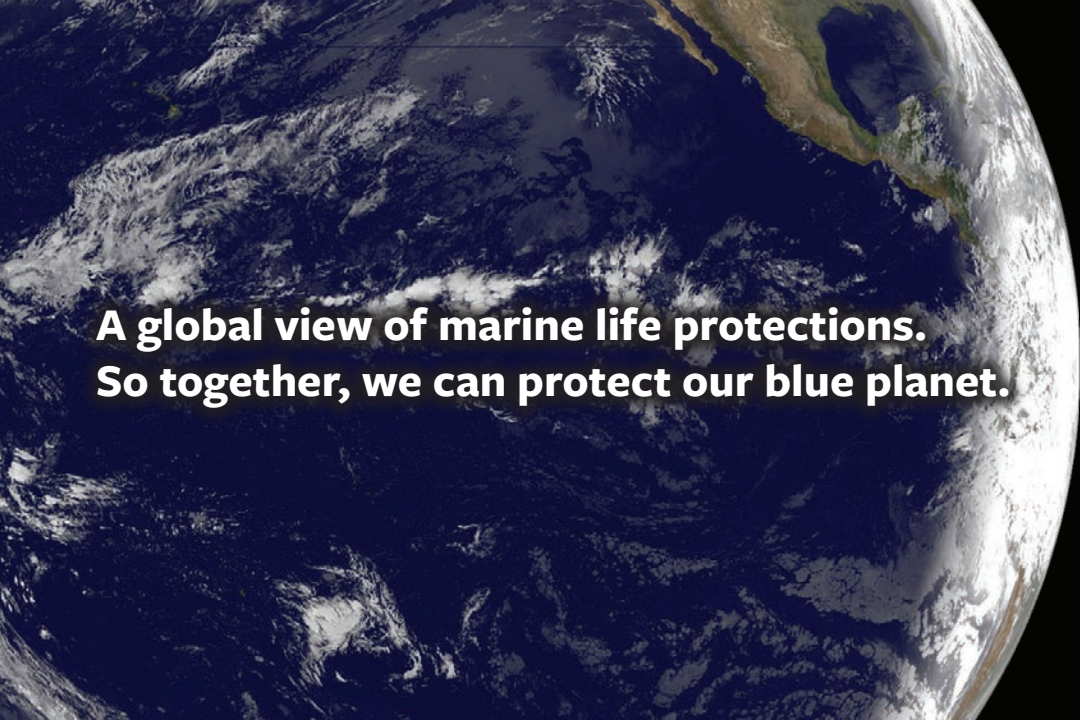


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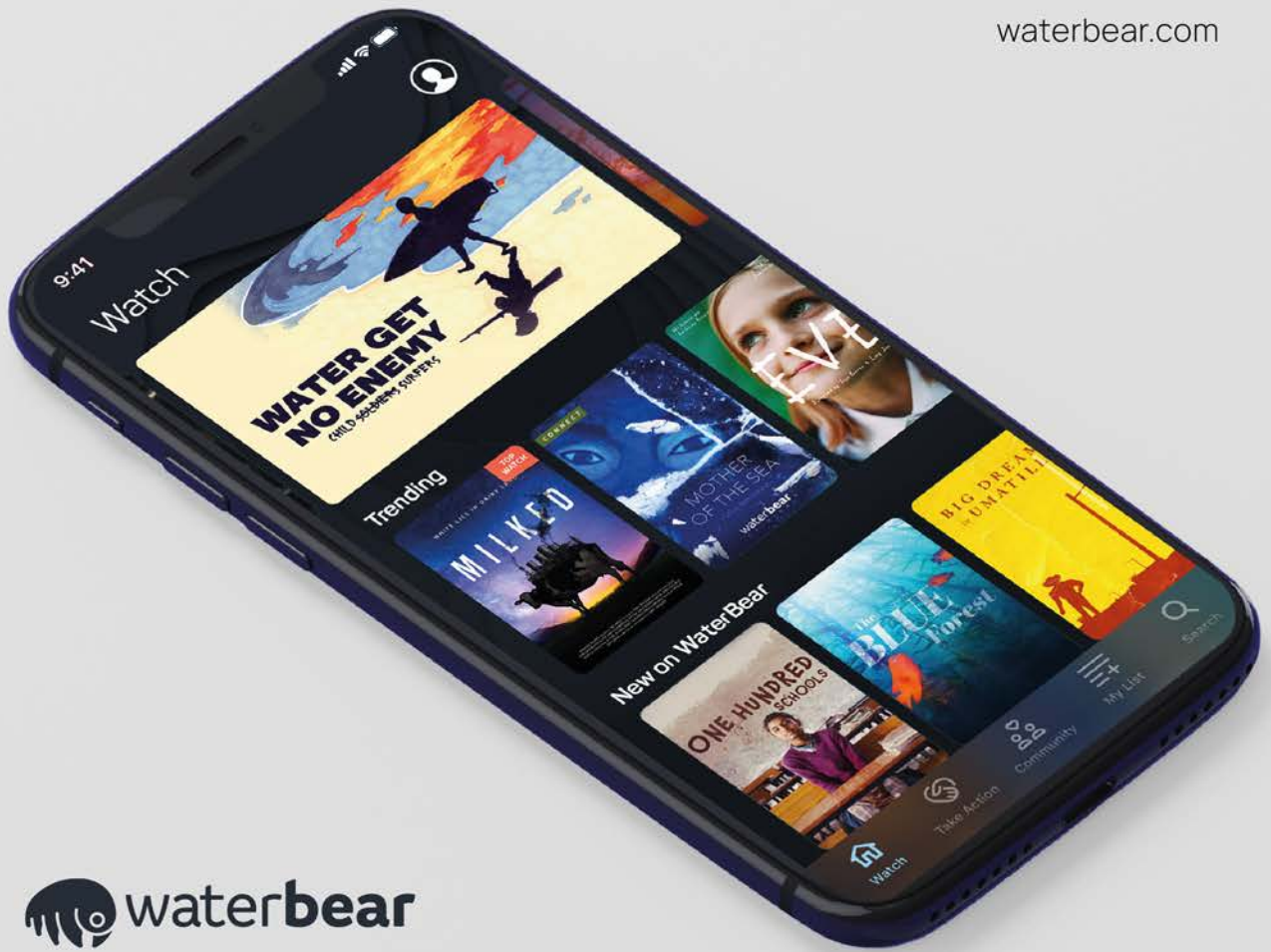
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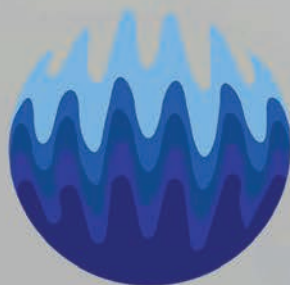


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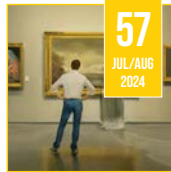
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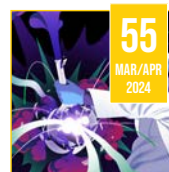
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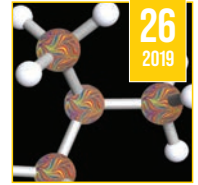
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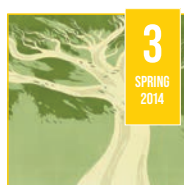
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Snakes Break All the Rules

Stephen S. Hall on writing his new book Slither: How Nature's Most Maligned Creatures Illuminate Our World

BY STEPHEN S. HALL

1

SNAKES ARE REVEALING NEW BIOLOGICAL MARVELS UNDER THEIR SKIN

Many of the most remarkable qualities of snakes have remained invisible to us until recently. Many people knew that pythons could ingest prey as large as deer or pigs, for example, but until recently no one knew *how* they did that. Genomic research has shown that pythons activate roughly 2,000 genes within minutes of consuming a meal. They can genetically enlarge organs like the heart, intestine, liver, and kidneys to process these huge meals, then genetically whittle away the extra tissue when they no longer need it.

Python genomes also possess suites of related genes that allow rapid adaptive changes in skull anatomy (allowing snakes to ingest food literally larger than their heads), cold-hardiness, and metabolism. The popular perception of evolution is that it takes place in time scales of thousands or millions of years; in snakes, natural selection can drive changes in as little as a few years.

2

SNAKES BREAK ALL THE RULES

Most vertebrate groups follow fairly consistent biological rules. We all know snakes are different—legless, elongated fuselages, cryptic behavior, the ultimate zoological Other. But I had no idea how many biological rules they appear to break.

Reproduction is probably the most obvious example. Scientists have known for a long time that some snakes bear live young, others lay eggs, and still others can clone themselves through parthenogenesis. But molecular research in the last couple years has shown that snakes are agnostic when it comes to the organization of their sex chromosomes. Some have chromosomes that resemble those of birds; others have chromosomes that resemble those of mammals. Further, male snakes have two penises (called hemipenes); females can store sperm in their bodies for up to eight years and delay reproduction for nearly a decade. As genome scientist Daren Card put it, “There are just no rules anymore,” when it comes to snakes.

3

SNAKES HAVE HISTORICALLY BEEN OBJECTS OF NOT JUST LOATHING BUT VENERATION

It's no secret that snakes are widely loathed and feared—they are often cited in psychological surveys as the most detested of all animals. But I was surprised to learn that the great cultures of antiquity in Egypt, Greece, and Mesoamerica also revered snakes. Asclepius, a Greek demigod and physician, inspired a cult of healing around the fifth century B.C. in Greece that spread throughout the Mediterranean. The cult became associated with serpents because Asclepius was said to have learned the secret of bringing the dead back to life from a snake. That is why the universal symbol of medicine, pharmacies, and medical aid societies throughout the world is the snake curling around the staff of Asclepius. The worship of Asclepius was so significant that Christianity took pains to suppress it and to demonize serpents, in scripture and art, which is one of the reasons humans learned to hate snakes. 🐍



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