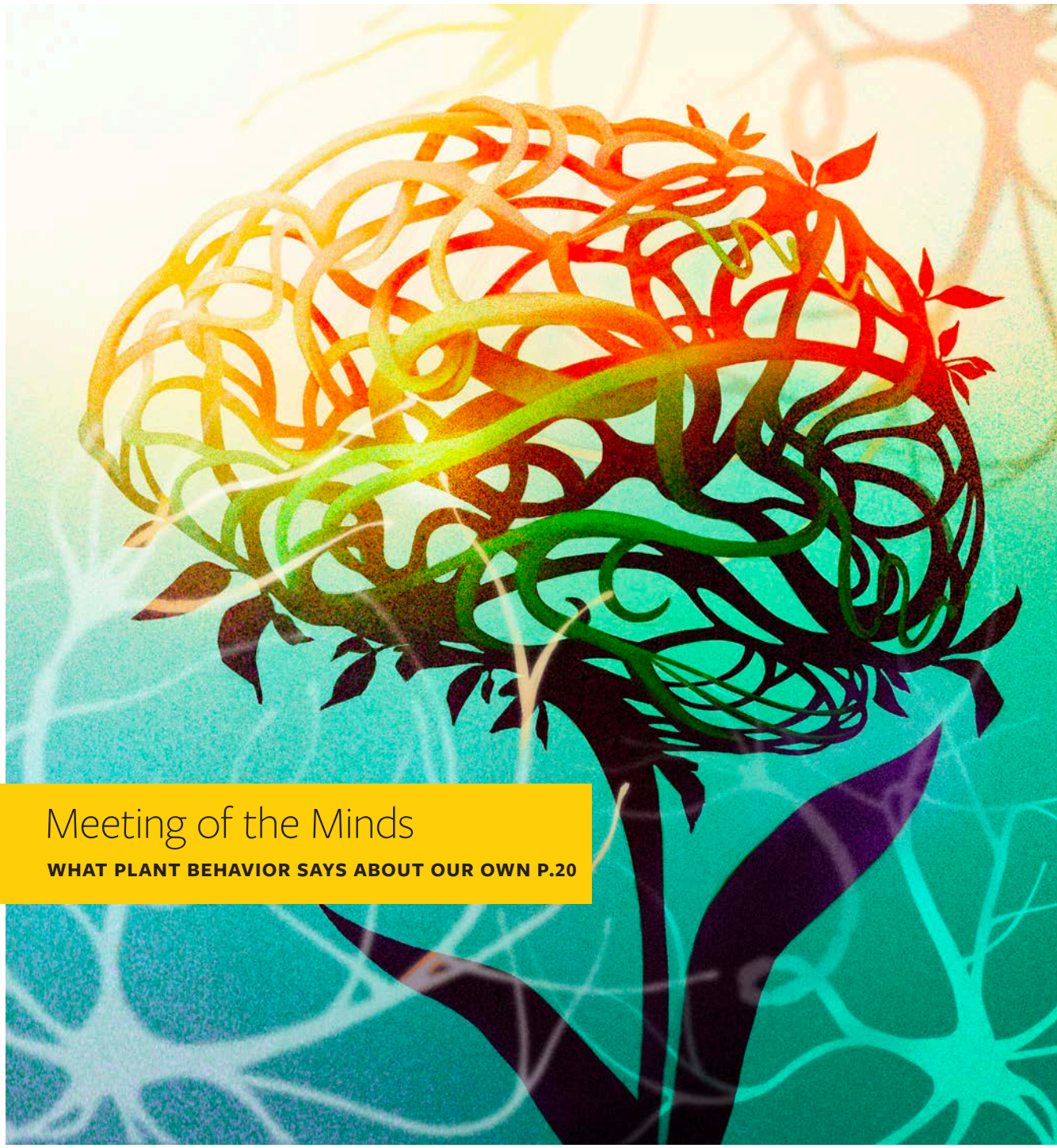
NAUTILUS

THE INCREDIBLE VOID
What lurks in empty space

A PILL FOR THE BROKEN-HEARTED
New hope for lovesickness

WHY MUST WE AGE?
Evolution is a cruel mistress



Meeting of the Minds

WHAT PLANT BEHAVIOR SAYS ABOUT OUR OWN P.20

The eightfold way. (1)

1-14-61

Review of the eight-group and its possible application to baryons, PS mesons, and

> "Working on a mathematics problem for a long time and then coming up with an answer, it's like a lost animal coming in out of the rain. You just want to say, *there you are*."
>
> CORMAC MCCARTHY, SFI AUTHOR & TRUSTEE

real C_{ijk} is totally antisymmetric (because trace). In mathematical language, we have the Killing form of our simple Lie algebra made real and compact.

A cross-product is now defined for eight-vectors. $\underset{\sim}{a} \times \underset{\sim}{b} = \underset{\sim}{c}$.

$C_{ijk} a_j b_k = c_i$. $\underset{\sim}{\uparrow} \times \underset{\sim}{\uparrow} = 2i \underset{\sim}{\uparrow}$ $\underset{\sim}{\frac{\uparrow}{2}} \times \underset{\sim}{\frac{\uparrow}{2}} = i \underset{\sim}{\frac{\uparrow}{2}}$.

In a particular representation, we have

$\uparrow_1 \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

$\uparrow_2 \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

$\uparrow_3 \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

$\uparrow_4 \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$

$\uparrow_5 \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix}$

$\uparrow_6 \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$

$\uparrow_7 \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix}$

$\uparrow_8 \begin{pmatrix} \frac{1}{\sqrt{3}} & 0 & 0 \\ 0 & \frac{1}{\sqrt{3}} & 0 \\ 0 & 0 & -\frac{2}{\sqrt{3}} \end{pmatrix}$

$[\uparrow_1, \uparrow_2] = 2i \uparrow_3$
$[\uparrow_2, \uparrow_3] = 2i \uparrow_1$
$[\uparrow_3, \uparrow_1] = 2i \uparrow_2$
$[\uparrow_4, \uparrow_5] = 2i \left(\frac{\sqrt{3}}{2} \uparrow_8 + \frac{\uparrow_3}{2} \right)$
$[\uparrow_6, \uparrow_7] = 2i \left(\frac{\sqrt{3}}{2} \uparrow_8 - \frac{\uparrow_3}{2} \right)$
$[\uparrow_1, \uparrow_8] = 0$.
$[\uparrow_2, \uparrow_8] = 0$
$[\uparrow_3, \uparrow_8] = 0$
$[\uparrow_4, \uparrow_8] = -\frac{\sqrt{3}}{2} 2i \uparrow_5$
$[\uparrow_5, \uparrow_8] = \frac{\sqrt{3}}{2} 2i \uparrow_4$
$[\uparrow_6, \uparrow_8] = -\frac{\sqrt{3}}{2} 2i \uparrow_7$
$[\uparrow_7, \uparrow_8] = \frac{\sqrt{3}}{2} 2i \uparrow_6$

$[\uparrow_1, \uparrow_4] = 2i \uparrow_7/2$
$[\uparrow_1, \uparrow_5] = -2i \uparrow_6/2$
$[\uparrow_2, \uparrow_4] = 2i \uparrow_6/2$
$[\uparrow_2, \uparrow_5] = 2i \uparrow_7/2$
$[\uparrow_3, \uparrow_4] = 2i \uparrow_5/2$.
$[\uparrow_3, \uparrow_5] = -2i \uparrow_4/2$
$[\uparrow_4, \uparrow_6] = 2i \uparrow_2/2$.
$[\uparrow_4, \uparrow_7] = 2i \uparrow_1/2$.

BACKGROUND IMAGE: These notes, written by Murray Gell-Mann circa 1961, include his enumeration of the eight so-called Gell-Mann matrices which form the basis for the Quark model — a model he described as The Eight-Fold Way and for which he was awarded a Nobel Prize in 1969.

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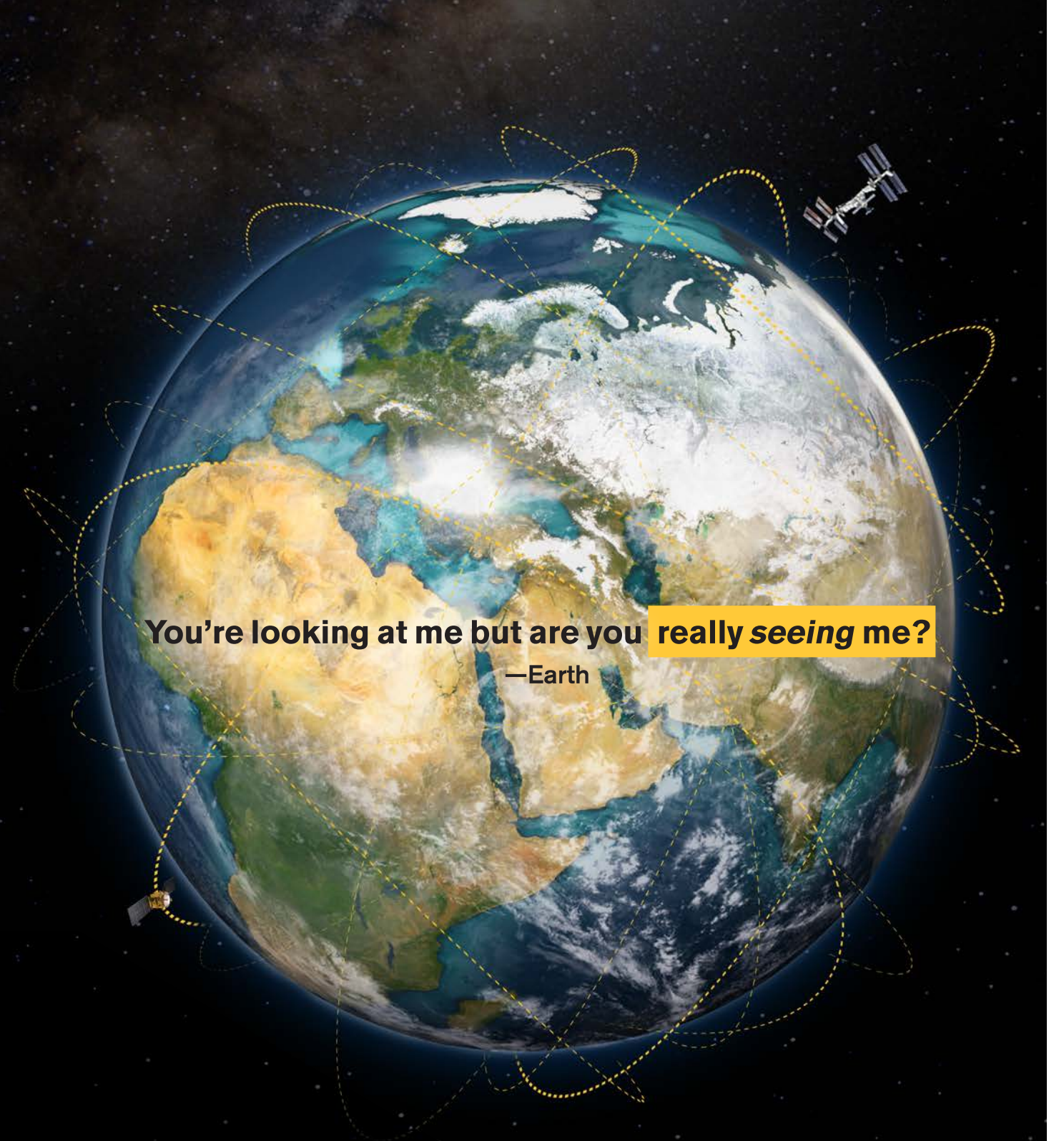
COVER Deena So'Oteh



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Reshaping our relationship with our world

Features

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The Highest Truth

BY KEVIN BERGER

EVEN IF WE CAN change a memory, should we?

It's a profound question. It's about the core of humanity. At times, science can reduce us to machines. Under the hood, we have the same parts, more or less. The neurochemicals that fuel the brain, including the creation and recall of memories, work pretty much the same way in everybody.

The lords of existentialism worried about this kind of rational objectification. If we're like everybody, we're nobody. Individual life has no meaning. Or that's what I think the irascible Kierkegaard meant, waving his cane at passersby in the Copenhagen streets, when he said that "objective uncertainty," that is, subjectivity, is "the highest truth attainable for an existing individual."

As I read the great Dane, personal memories constitute the core of our subjectivity and help color the world in a sacred way. That's a beautiful thought.

The question of whether we should change a memory comes in this issue's article, "This Drug Can Mend a Broken Heart." Writer Shayla Love explores a recent therapy called "memory reconsolidation." It doesn't erase memories to create an eternal sunshine of a spotless mind, it exploits the innate plasticity of our gray matter to blunt the sting of traumatic memories. The existential importance of individual memories remains.

Getting to the core of who and what we are is a central mission of science, and a theme that runs through this issue.

In our cover story, "What Plants Are Saying About Us," philosopher Paco Calvo tells writer Amanda Gefter that plants sense and respond to their environments like we do. They embody a proto sentience. Calvo, through the lens of evolution, is getting back to basics. Way back. Steve Horvath is, too. In "The Universal Clock of Aging," the geneticist explains how Father Time ticks away in our DNA, inevitably wearing our bodies down. Astrophysicist Paul M. Sutter takes us deeper still, to empty space—between stars, between atoms—to explain the energy that animates everything.

These articles may sound like objectification. We could look at Carl Sagan's remark, "We are made of star stuff," through a dark lens. We are nothing more. But that universal essence is something to celebrate, don't you think? We are not alone, defined by fear and trembling. We are the stars, the plants, the animals. We are everything.

In "ChatGPT Is a Mirror of Our Times," writer Philip Ball explains that AI language is a clever beast created by humans and has cast a spell over our culture. The existentialists are right on this one: The fear we're machines runs deep. Ball, though, relieves the dread by explaining how AI language works. Its shortcomings, he writes, reveal "what cannot be automated and algorithmized: in other words, what constitutes the core of humanity."

Which brings me to "The Ghostwriter" in this issue, a work of fiction, where the highest truth often lies. The futuristic story is set in San Francisco, where mechanized holograms populate the city to the narrator's dismay. Disheartened, she realizes there is only one thing she can do to preserve the core of humanity.

Happy reading.

"Sails of Change supports #30x30,
a global call to protect 30% of our planet by 2030.
To do so, we must Inspire, Unite, Change.

- Dona Bertarelli, Founder of Sails of Change

sails of change

Change starts with imagination[5]

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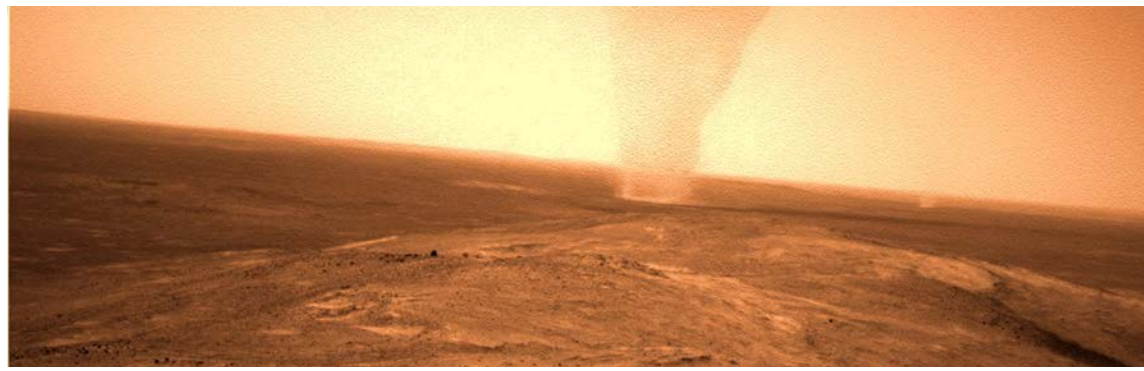


GEOSCIENCE

The Wind on Mars

WHEN I FIRST HEARD IT, it sounded like a brief, blustery outtake. A momentary lull in an outdoor event captured by an old camcorder. A sonic slice of a windy afternoon anywhere on Earth.

The sound was indeed wind whipping past a microphone. But wind on another planet. Wind on Mars. The recording, released by NASA in December 2022, is the first time humans have ever heard a Mars-made sound.

Scientists have known for years that the surface of the Red Planet is alive with wind, which creates spiraling dust devils—and planet-engulfing megastorms. But until now they've had to watch these events unfold in frustrated silence. "It's like you've experienced something with one of your senses for a long time, but you've never experienced it with another," says Roger Wiens, a professor of planetary science at Purdue University. "And now we have that second sense experience."

Wiens is a coauthor of the recent paper describing NASA's new earworm as well as the lead scientist for the NASA Perseverance rover's suite of observational tools, known collectively as the SuperCam, designed to gather new information about Mars.

To conserve resources, the rover's microphone is rarely listening—it was on for less than 85 minutes for the entire first year of the mission. But on Sept. 27, 2021, at 11:02 local Mars time, it just happened to be cycling through one of its short listening bursts when a dust devil, some 387 feet tall, swept not just nearby but across the rover itself. And the microphone, located "*almost* at a human ear level" Wiens points out, picked up not only the two sides of the devil and its quiet eye, but also the sound of its dust.

"It's one thing to hear a gust of wind, but to know that it's a part of this pattern of dust devils that we have seen for many years on Mars, that was like a dream come true," says Wiens.

SOUND MIGHT SEEM a rather low-fi channel with which to gather data from our solar system, when our rovers are outfitted with lasers, ground-penetrating radar, and X-ray fluorescence spectrometers. But to Wien's ears, sound is rich with information that is otherwise elusive.

In the recording, "we actually could hear sand grains pummeling the rover," Wiens says. "The wind itself tends to make a low pitch, and then the sand grains hitting a higher pitch." The scientists used those discrete sounds to estimate the density of dust grains in the entire dust devil.

NASA / JPL

And there is one sound in this recording that he and his colleagues are still straining to decipher. "There's one sort of loud snap in the middle," he says. It could either be a grain of sand hitting the microphone directly—or an electrostatic pop, from the charging that happens in these bone-dry dust clouds.

Sound is exceedingly rare in the universe.

The full weather station on Perseverance was also up and running at the time of the dust devil's passage, so scientists were able to match the sound recording with temperature, pressure, and wind speed and direction. Writing in Nature Portfolio's Astronomy Community, Alexander Stott, a coauthor of the paper and a postdoctoral researcher at the University of Toulouse, observed that precisely 199 years before this Martian gust was recorded, on the very same day in September, the French linguist Jean-François Champollion reported that he had decoded the Rosetta Stone. "In a similar way, the Perseverance rover employs multiple techniques and measurements to decipher the Martian atmosphere," Stott wrote.

When we hear wind on Earth, what we are hearing—aside from its impact on objects around us (leaves brushing against one another, for example)—is primarily the jumble of the atmosphere's rushing molecules themselves as they get knocked off their course by the structure of our ears. (We can shape this sound by turning our heads into or away from—or perpendicular to—the wind, creating different amounts and types of turbulence around our ears.) The same physical dynamics, as it turns out, are at play with a microphone on Mars. "It's making that turbulent sound as it's flowing past the corners of the box," Wiens explains.

The interesting thing about wind on Mars is that, despite the menacing appearance of the dust storms it generates, it is actually quite gentle. With atmospheric pressure just 1 percent of Earth's, even the planet's stiffest gust, of 60 miles per hour, packs no punch and would likely feel like little more than a gentle waft to us. (Which offers reassurance that the setup for *The Martian*—in which a violent windstorm causes such severe damage that it essentially strands a scientist—would never befall any real operations there.)

This low density of gas molecules is likely the reason for the frequent dust devils on Mars. Just like on Earth, Martian molecules like to flow from high pressure to low. These pressure disparities arise when there are sizable differences in temperatures. Because the air molecules on Mars are so few and far between, they're not able to retain heat from the sun as effectively as the more densely packed ones here in our atmosphere. So there is a dramatic temperature gradient above the ground—often spanning 35 degrees Fahrenheit in several feet. "So it could be mildly warm down by your feet, and your eyelashes could have frost on them," Wiens says. These hyperlocal temperature differences create just the right conditions to kick up swirling dust devils.

Weak and dust-filled as it is, this wind is actually a helpful collaborator. The dust on Mars contains superfine particles, just the type that can coat the solar panels that power much of the surface-based science. So a gust here and there can help clear off these essential components. Which has added unexpected longevity to some of humanity's missions. In January 2004, NASA rovers Spirit and Opportunity landed on Mars with life expectancies of about 90 days. At the time, we "were not aware that the dust devils would come along and clean those panels off," Wiens says. But the two rovers plodded along on Mars' blustery surface until 2010 and 2018, respectively. Not all areas of the planet, though, are as breezy. The InSight lander, which arrived on the flat plain of Elysium Planitia in late 2018, powered down in late December 2022 because accumulated dust ultimately blocked the sunlight.

EARTH IS a noisy planet. But without life, sounds here would be limited to those of wind and water and the occasional geological event. On Mars the only likely homespun sound to listen for is wind. (Most other sound studies on Mars have been from human-cued noises: plasma laser zaps, rotating helicopter blades.) Learning about sound on other planets can help scientists understand more about how they could use these pressure waves in future research.

But sound is exceedingly rare in the universe. It needs fairly tightly packed particles—like those in an

atmosphere—to propagate. "So the moon is no good for that," Wiens says. Neither is Mercury. Even supernovae are essentially silent. When I ask what he would pick if he could listen to anything in the galaxy, he pauses for a moment to consider places that might have sound.

Finally, he lands on Titan, one of Saturn's more alluring moons. Which is perhaps no coincidence. NASA is currently building a helicopter, named Dragonfly, that will begin its journey to Titan in just a few years. Dragonfly will be equipped with microphones for careful listening, and perhaps not just for wind. Scientists suspect Titan has super-cold liquid methane on its surface. "So if we're really lucky, we would hear the sound of liquid, as well as the sound of wind. But who knows," Wiens muses.

For now, Perseverance will keep listening, a few fleeting moments at a time, on Mars. And any new sounds it picks up will hopefully bring novel insights about atmospheres and physics beyond our own planet, Wiens says. Because driving all of this, he tells me, is not just intel gathering for future basecamps on Mars, but also, "a curiosity about how the physics of the universe works."

—Katherine Harmon Courage

SOCIOLOGY

Yes, Your Loud Neighbors Are Driving You Bonkers

CLASSICVECTOR / SHUTTERSTOCK

YEARS AGO, my fiancé and I found a dream apartment in Brooklyn. With high ceilings and spacious rooms, it sat next to an urban garden so that trees and shrubs peeked into our windows. Yet we soon discovered a big problem. Our upstairs neighbors had two little boys who woke up around 6 every morning and started tossing toys, throwing balls, and chasing each other. Around 6 in the evening, as we got home from work, a similar routine began, and lasted all evening.

For about a year, we tried to become immune to noise. After all, we were seasoned Brooklynites, used to honking, car alarms, and fire truck sirens. We tried to ignore the sounds, play music, and keep the TV on. Still, we became increasingly irritable and aggravated, which led to fights. With the arrival of our own baby, we had to move. Our new apartment overlooked a gas station, but at least there were no bangs from above. For a long time, I considered our retreat a weakness of character. If we weren't so abnormally sensitive, we'd still be enjoying our lush green paradise.

Turns out, we weren't abnormally sensitive at all. Our reaction to the noisy upstairs neighbors was on par with everyone else's. Residents of multistory apartment buildings regularly suffer from what acoustic scientists call "impact sounds"—distinct sounds of short durations like bangs, thuds, and thumps. One study has noted that floor impact sounds were the most annoying noise type in apartment buildings—and were generated primarily by children between 6 and 9 years old.

We have evolved to notice sounds in case they bring danger.

Recently, a team of researchers led by Markus Müeller-Trapet of Canada's National Research Council designed a series of experiments to simulate and measure people's perceived annoyance from a noisy upstairs neighbor. In a two-floor setting, they recorded about 60 different sounds, including everything from walking barefoot to bouncing a ball to dropping a hammer. They played the sounds to about 100 participants in Canada, Germany, and Korea, who rated their levels of annoyance from zero to 100. "The results differed a little bit, but the bottom line was always the same," says Müeller-Trapet. People hated loud steps, ball-bouncing, and, naturally, hammers. As I listened to the recordings, I was stressed and grumpy, just like I used to be in my old apartment.

Why are we so sensitive to these impact sounds, as opposed to continuous ones like music or a steady hum? "The traditional definition of noise is unwanted sounds," says Mathias Basner, a professor of psychiatry and neuroscience at the University of Pennsylvania School of Medicine. People who go to rock concerts don't mind loud music because they expect it. Loud neighbors, on the other hand, disrupt what we're doing, break our focus or concentration, and annoy us to no end. Try as we might, we can't tune them out.

We have evolved to notice sounds in case they bring danger, so our auditory system is constantly on, even when we are asleep. Unexpected noise means an abrupt change in our surroundings. "A change in the environment is a potential danger signal," Basner says—think of the arrival of a predator or a falling rock. In the old days of living on the savannah, we would weigh our survival tactics, choose between fight or flight.

Today, even if we don't fight or flee when our neighbors drop a hammer, our bodies mount the same physiological response. We release stress hormones like adrenaline and cortisol. Our peripheral blood vessels tighten, our heart rate goes up, and our intestines stop their normal movement for a little while—so that all of our blood is available to the skeletal muscles to maximize strength or speed. Even the blood itself changes in such a way that it coagulates easier, says Basner—in case we bleed. "All of these are precursors of cardiovascular disease," he says.

Research has linked neighbor noise annoyance with a host of mental and physical health symptoms. And although it looked at unwelcome noises in general, another study found that exposure to noise messes up our central nervous system, leading to emotional stress and anxiety and increases the risk for depression, cognitive impairment, and neurodegenerative disorders.

According to the United Nations, by 2050, two out of every three people will likely be living in urban areas, so this problem will only get worse. "The more we have these huge apartment buildings, the more we will need a good protection from these types of sounds," says Müeller-Trapet, whose team aims to help develop better building codes to make urban dwellings more soundproof. "Our goal is to provide some design guidance to all the builders." Until then, annoyed tenants may have look for quieter apartments like we did. It was a smart move—and a healthy one—after all.

—Lina Zeldovich

ASTRONOMY

Should People Live on the Moon?

One question for Joseph Silk, an astrophysicist at Johns Hopkins University.

Should people live on the moon?

Why not? We have to start somewhere if we ever want to leave Earth. And the only realistic place to start is the moon. It's going to be for a minority, right? For explorers, for people exploiting the moon for commercial reasons, for scientists. They'll be living on the moon within the next century. And it will be a starting point to go elsewhere. It's a much easier environment, because of the low gravity, from which to send spacecraft farther afield.

NOSTALGIA FOR INFINITY / SHUTTERSTOCK

A giant lava tube is large enough to house an entire city.

If your interest is commercial, then you'll probably focus on mining because we're running out of certain elements on Earth critical for our computer industry. There's a hugely abundant supply on the moon, thanks to its history of bombardment by meteorites. Beyond that there's tourism. You can already buy tickets—not cheap, of course—for a trip around the moon, because of people like Elon Musk. The moon's also got a huge abundance—this is not very widely known—of water ice. Inside deep, dark craters. Not only does that help you have a major resource for life, but maybe the most important use of water will be to break it down into oxygen, hydrogen. Liquefy these—you have abundant power from the sun to do this—and lo and behold, you have rocket fuel to take you throughout the inner solar system and beyond.

I'm very attracted to the moon as a place to build telescopes. We can see stars really sharply, with no obscuration. Water vapor in Earth's atmosphere masks out much of the infrared light from the stars where there's huge amounts of information about what the stars are made of. Also, because of our ionosphere, Earth is a very difficult place to receive low-frequency radio waves. These are inaccessible from Earth because we'll be looking deep into the universe, where these waves get stretched out by the expansion of the universe. Earth's ionosphere distorts them. So, on the moon, we can view the universe as we never could before.

The only way to capture these really faint things is with a huge telescope. The James Webb is a small telescope—six meters. The far side of the moon is a unique place for doing that, and there are some futuristic schemes now to build a mega telescope inside a crater, a natural bowl. You can line the inside of that bowl with a number of small telescopes, maybe hundreds of them, and they would operate coherently, supported by wires from the crater edges. The size of the telescope determines how much light you can collect. You could have hundreds of times more light-gathering power on the moon.

Suddenly you have a telescope that's kilometers across, and this would be the most amazing thing I could imagine, because then you could have not just light-collecting power, but resolving power. You could actually directly image the nearest exoplanets and look to see: "Do they have oceans? Do they have forests?" The first things you want to look for, if you want to explore the possibilities of distant, alien life. I'm rather doubtful that we'll find life in our solar system. We have to look much farther away. Many light-years away. And that we can do with these giant telescopes.

The people working on the moon will have to figure out how to make a biosphere. Could be inside an artificial construction on the lunar surface. But that will not be very large. A much more promising approach, again in the next decades, will be to use a giant lava tube. These are huge, natural caves, relics of ancient volcanic activity. A giant lava tube is large enough to house an entire city. You can imagine air proofing that and developing a local atmosphere inside that, which would be a great place to live and certainly do new things on the moon. Things you would never do on Earth.

That is my most optimistic scenario for having large numbers of people. By no means millions, but maybe thousands of people living and working on the moon. One has to be optimistic that the international community will recognize that cooperation is the only way to go in the future, and establish lunar law that will control both real estate and also, I imagine, crime activity, if people start disputing territories. I'm hoping we have a legal framework. Right now, we seem very far away from this, but it's got to happen. We have maybe one or two decades before the moon becomes a competitive place and exploration heats up.

—Brian Gallagher

ZOOLOGY

The Vanishing Animals of Hispaniola

SCUTTLING THROUGH THE BRUSH in the dark Dominican Republic night, a rare Hispaniolan solenodon comes into view in the sudden beam of a flashlight. This small animal has an exaggerated shrewlike snout and is one of the few venomous mammals on Earth. Hispaniolan solenodons live mostly off of insects, seeking protection in their burrows during the day and foraging at night. But their numbers are few, and their species status has been fragile.

One of only two surviving endemic mammals on the Caribbean island of Hispaniola, the solenodons depend disproportionately on conservationists in the Dominican Republic. With the island's other nation of Haiti in dire political and economic straits, conservation work has largely fallen on the eastern nation's shoulders. As it has for many of the island's other unique endemic species. From the striking jewel-toned broad-billed tody to the charismatic endangered rhinoceros iguana, animals of Hispaniola have been facing pressures from agriculture, poaching, development, feral predators—and collisions with humans: The Dominican Republic alone, with a population of just over 11 million people, hosts more than 7 million tourists each year.

Islands and their endemic species have long been essential in helping us understand evolution. Since Charles Darwin's 19th-century visit to the Galapagos Islands and his observations of their now-famous finches, scientists have relied on unique island animals to help piece together the winding tale of speciation. Now islands are showing us a new side of change: the impact human interference has on endemic species' evolutionary trajectories. Island animals are uniquely vulnerable to encroachment. "A high jeopardy of extinction comes with territory," David Quammen writes in *The Song of the Dodo*. "Islands are where species go to die."

But it doesn't have to be that way. Working to protect their local species, Dominican Republic conservationists have spent decades diligently dismantling poachers' traps, tracking populations, and fighting to protect key habitat from development. With all of this work, animals like the Hispaniolan solenodon and the rhinoceros iguana now might have a fighting chance.

As a wildlife conservation photographer, I had the fortune of visiting the Dominican Republic last year and venturing out alongside some of these conservationists to document their work—and the striking animals they are helping to protect.

Despite their endangered status, rhinoceros iguanas are still sometimes captured for human consumption in Haiti—and often eaten by feral dogs, cats, and mongooses throughout Hispaniola. But at Lago Enriquillo National Park in the southwest of the Dominican Republic, the lizards are free to roam in relative peace. Eating plants and warming themselves in the arid landscape, they can grow up to 4.5 feet long and weigh up to 20 pounds.

But even here, within the park's protected boundaries, I learned that the iguanas are not entirely free from human-caused hazards. The area is riddled with makeshift traps set by poachers, jury-rigged from string and logs, poised to ensnare the iguanas emerging from their dens.

Dedicated park rangers, including Jerbin Volquez, are working hard to clear

Hispaniolan solenodon (*Solenodon paradoxus*)

TAMARA MARIA BLAZQUEZ HAIK

these traps. We spotted one such trap right after entering the park, which Volquez quickly disassembled. "When the iguanas come out of their dens, they get caught up in the strings," he explained. Although the poachers typically capture the iguanas live to sell as pets or in the exotic animal trade, "sometimes the poachers take too long to come back and check their traps, and the iguanas starve to death."

Other threats to these even-keel iguanas come in the more innocuous form of curious tourists. As people flock to the park's stunning saltwater lake, they encounter these vegetarian lizards and offer them snacks. Such routine feeding has made rhinoceros lizards not only unwary of humans, but also sick from eating their food.

Another danger is apathy from national authorities, which continue to authorize developers to build in or around the habitats of these animals outside of the park, further reducing their crucial homeland.

The solenodon is a curious animal, a relic of sorts, and has been darting along its own evolutionary path since the late Cretaceous. Although solenodons were common throughout North America millions of years ago, they now persist only on the islands of Hispaniola and Cuba. Their long history allowed them the time to develop their own venomous hunting strategy—a newly cracked case of convergent evolution.

Since their first scientific description in the mid-19th century, the Hispaniolan solenodon's official status has wavered. Part of the challenge is in finding the animals.

A nighttime trip to Sierra de Bahoruco National Park and the guidance of its head ranger, Nicolás Corona, made it possible on my visit. Colá, as Corona is known locally, had just finished fighting a wildfire nearby and was eager to help us check in on the impact on his beloved solenodons.

Although Colá was once a hunter, he eventually found more purpose as a park ranger. He has now been working to protect Hispaniolan solenodons for three decades and has made a name for himself as one of their key experts in the international scientific community, appearing in the acknowledgement section of countless journal papers about the animals. In part because he has a special acuity for finding these elusive animals.

Rhinoceros iguana (*Cyclura cornuta*)

Like the hunter he once was, he waits, in quiet darkness, until he hears the tiny steps of the solenodon on the leaf litter. Their odd zig-zag traveling pattern makes their footfalls easy to distinguish from other small quadrupeds. Once he can sense the animal is near, he flashes his light on them, causing them to freeze in their tracks—and allowing him to carefully pick them up for examination or research before releasing them.

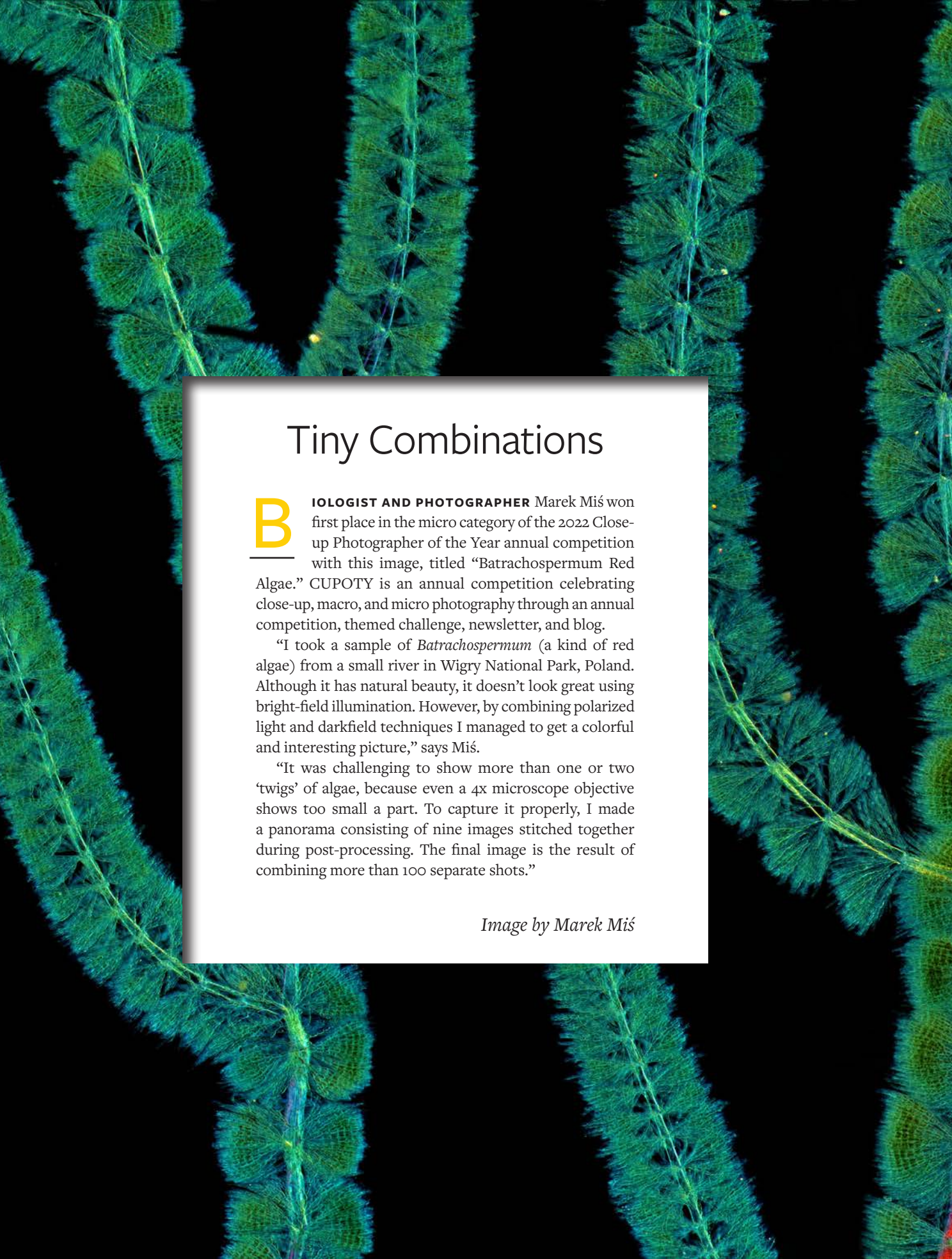
The night of my visit, Colá and his fellow rangers, still covered in soot from their firefight, instructed us to turn off all lights and wait, while they ventured quietly into the woods. In less than 40 minutes, we heard a whistle and saw Colá and his team emerge from the woods. "We found two! A male and a female!" he shouted with a huge smile on his face, which was now relaxed with relief that the nearby fire hadn't decimated the local population.

In 1981, the Hispaniolan solenodon was declared functionally extinct, and as recently as 2020 it was considered endangered by the International Union for Conservation of Nature. Thanks in large part to the work of Colá and his colleagues, the IUCN has recently promoted it to "least concern." But due to concern over its populations outside of the park, the Dominican Republic government still qualifies the unusual mammal as endangered to bolster conservation efforts.

Despite their successes, conservationists in the Dominican Republic remain concerned about the future of their endemic species in the face of the country's growing tourism industry. New hotels and tourism complexes continue to be built on delicate habitat. Still, Corona, Volquez, and countless others continue to fight for these iconic wildlife species.

—Tamara Maria Blazquez Haik

TAMARA MARIA BLAZQUEZ HAIK



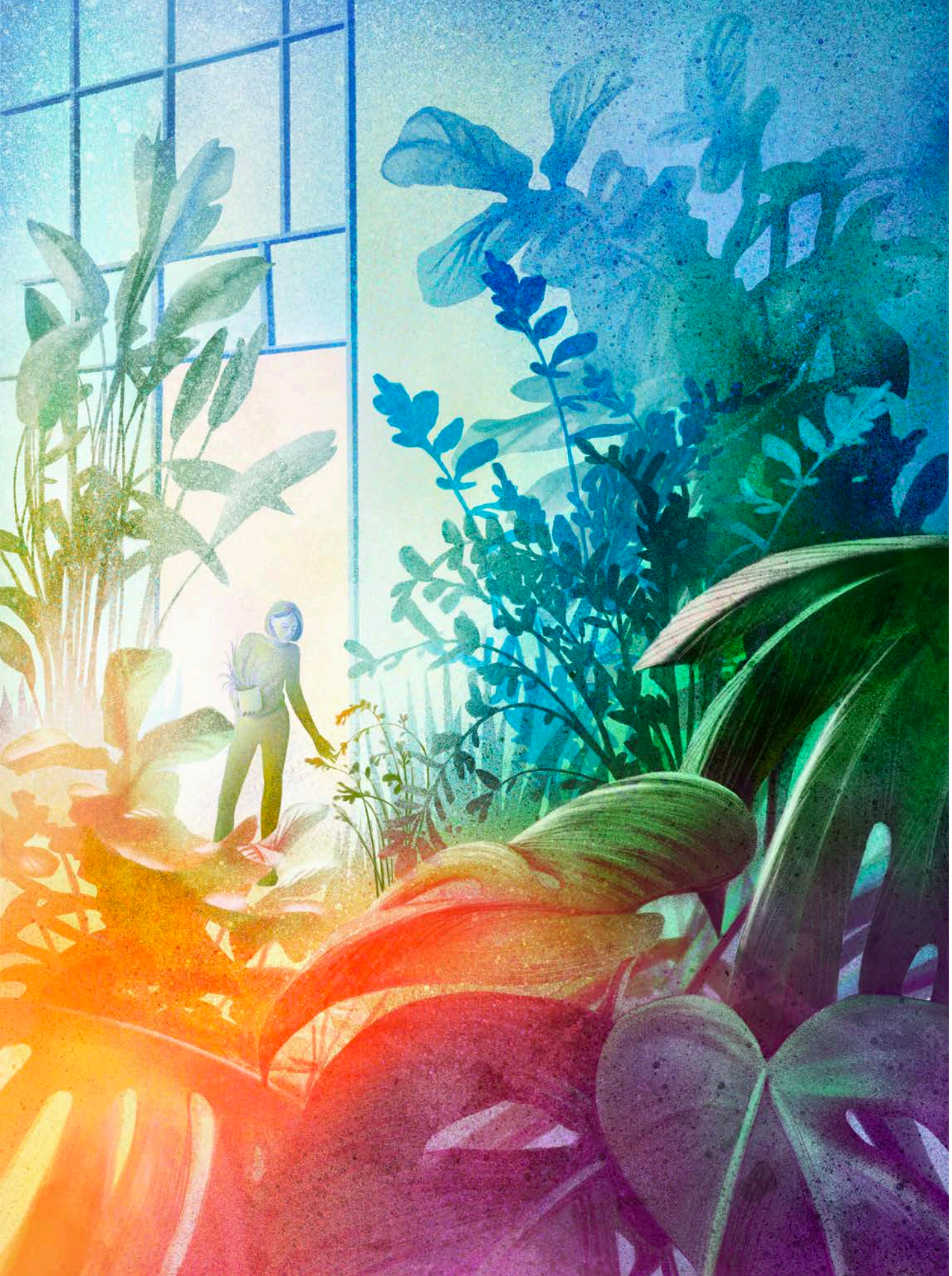
Tiny Combinations

BIOLOGIST AND PHOTOGRAPHER Marek Miś won first place in the micro category of the 2022 Close-up Photographer of the Year annual competition with this image, titled "Batrachospermum Red Algae." CUPOTY is an annual competition celebrating close-up, macro, and micro photography through an annual competition, themed challenge, newsletter, and blog.

"I took a sample of *Batrachospermum* (a kind of red algae) from a small river in Wigry National Park, Poland. Although it has natural beauty, it doesn't look great using bright-field illumination. However, by combining polarized light and darkfield techniques I managed to get a colorful and interesting picture," says Miś.

"It was challenging to show more than one or two 'twigs' of algae, because even a 4x microscope objective shows too small a part. To capture it properly, I made a panorama consisting of nine images stitched together during post-processing. The final image is the result of combining more than 100 separate shots."

Image by Marek Miś



What Plants Are Saying About Us

Your brain is not the root of cognition

BY AMANDA GEFTER

I WAS NEVER INTO HOUSE PLANTS until I bought one on a whim—a prayer plant, it was called, a lush, leafy thing with painterly green spots and ribs of bright red veins. The night I brought it home I heard a rustling in my room. Had something scurried? A mouse? Three jumpy nights passed before I realized what was happening: The plant was *moving*. During the day, its leaves would splay flat, sunbathing, but at night they'd clamber over one another to stand at attention, their stems steadily rising as the leaves turned vertical, like hands in prayer.

"Who knew plants do stuff?" I marveled. Suddenly plants seemed more interesting. When the pandemic hit, I brought more of them home, just to add some life to the place, and then there were more, and more still, until the ratio of plants to household surfaces bordered on deranged. Bushwhacking through my apartment, I worried whether the plants were getting enough water, or too much water, or the right kind of light—or, in the case of a giant carnivorous pitcher plant hanging from the ceiling, whether I was leaving enough fish food in its traps. But what never occurred to me, not even once, was to wonder what the plants were thinking.

ILLUSTRATION BY **DEENA SO'OTEH**

THE PLANT WHISPERER Paco Calvo once studied artificial intelligence to determine whether it could help unlock secrets of cognition. He decided it couldn't. Plants were the key.

COURTESY OF UNIVERSIDAD DE MURCIA

I was, according to Paco Calvo, guilty of "plant blindness." Calvo, who runs the Minimal Intelligence Lab at the University of Murcia in Spain where he studies plant behavior, says that to be plant blind is to fail to see plants for what they really are: cognitive organisms endowed with memories, perceptions, and feelings, capable of learning from the past and anticipating the future, able to sense and experience the world.

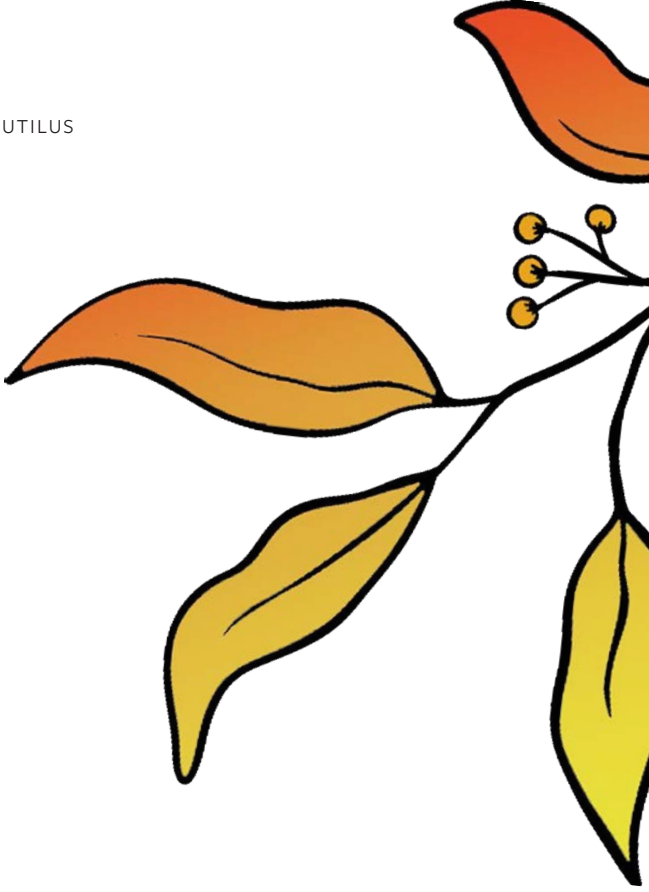
It's easy to dismiss such claims because they fly in the face of our leading theory of cognitive science. That theory goes by names like "cognitivism," "computationalism," or "representational theory of mind." It says, in short, the mind is in the head. Cognition boils down to the firings of neurons in our brains.

And plants don't have brains.

"When I open up a plant, where could intelligence reside?" Calvo says. "That's framing the problem from the wrong perspective. Maybe that's not how our intelligence works, either. Maybe it's not in our heads. If the stuff that plants do deserves the label 'cognitive,' then so be it. Let's rethink our whole theoretical framework."

CALVO WASN'T INTO PLANTS, either. Not at first. As a philosopher, he was busy trying to understand human minds. When he began studying cognitive science in the 1990s, the dominant view was the brain was a kind of computer. Just as computers represent data in transistors, which can be in "on" or "off" states corresponding to 0s and 1s, brains were thought to represent data in

To understand how human minds work, he started with plants.



the states of their neurons, which could be "on" or "off" depending on whether they fire. Computers manipulate their representations according to logical rules, or algorithms, and brains, by analogy, were believed to do the same.[1]

But Calvo wasn't convinced. Computers are good at logic, at carrying out long, precise calculations—not exactly humanity's shining skill. Humans are good at something else: noticing patterns, intuiting, functioning in the face of ambiguity, error, and noise. While a computer's reasoning is only as good as the data you feed it, a human can intuit a lot from just a few vague hints—a skill that surely helped on the savannah when we had to recognize a tiger hiding in the bushes from just a few broken stripes. "My hunch was that there was something really wrong, something deeply distorted about the very idea that cognition had to do with manipulating symbols or following rules," Calvo says.

Calvo went to the University of California San Diego to work on artificial neural networks. Rather than dealing in symbols and algorithms, neural networks represent data in large webs of associations, where one wrong digit doesn't matter so long as more of them are right, and from a few sketchy clues—*stripe, rustle, orange, eye*—the network can bootstrap a half-decent guess—*tiger!*

Artificial neural networks have led to breakthroughs in machine learning and big data, but they still seemed, to Calvo, a far cry from living intelligence. Programmers train the neural networks, telling them when they're right and when they're wrong, whereas living systems figure things out for themselves, and with small amounts of data to boot. A computer has to see, say, a million pictures of cats before it can recognize one, and even then all it takes to trip up the algorithm is a shadow. Meanwhile, you show a 2-year-old human *one* cat, cast all the shadows you want, and the toddler will recognize that kitty.

"Artificial systems give us nice metaphors," Calvo says. "But what we can model with artificial systems is not genuine cognition. Biological systems are doing something entirely different."

Calvo was determined to find out what that was, to get at the essence of how real biological systems

Plants can distinguish self from non-self, stranger from kin.

perceive, think, imagine, and learn. Humans share a long evolutionary history with other forms of life, other forms of mind, so why not start with the most basic living systems and work from the bottom up? "If you study systems that look way different and yet you find similarities," Calvo says, "maybe you can put your finger on what is truly at stake."

So Calvo traded neural networks for a green thumb. To understand how human minds work, he was going to start with plants.

IT TURNS OUT IT'S TRUE: Plants do stuff.

For one thing, they can sense their surroundings. Plants have photoreceptors that respond to different wavelengths of light, allowing them to differentiate not only brightness but color. Tiny grains of starch in organelles called amyloplasts shift around in response to gravity, so the plants know which way is up. Chemical receptors detect odor molecules; mechanoreceptors respond to touch; the stress and strain of specific cells track the plant's own ever-changing shape, while the deformation of others monitors outside forces, like wind. Plants can sense humidity, nutrients, competition, predators, microorganisms, magnetic fields, salt, and temperature, and can track how all of those things are changing over time. They watch for meaningful trends—Is the soil depleting? Is the salt content rising?—then alter their growth and behavior through gene expression to compensate.

Plants' abilities to sense and respond to their surroundings lead to what seems like intelligent behavior. Their roots can avoid obstacles. They can distinguish self from non-self, stranger from kin. If a plant finds itself in a crowd, it will invest resources in vertical growth to remain in light; if nutrients are on the decline, it will opt for root expansion instead. Leaves munched on by insects send electrochemical signals to warn the rest of the foliage,[2] and they're quicker to react to threats if they've encountered them in the past. Plants chat among themselves and with other species. They release volatile organic compounds with a lexicon, Calvo says, of more than 1,700 "words"—allowing them to shout things that a human might translate as "caterpillar incoming" or "*$@#, lawn mower!"

Their behavior isn't merely reactive—plants anticipate, too. They can turn their leaves in the direction of the sun before it rises, and accurately trace its location in the sky even when they're kept in the dark. They can predict, based on prior experience, when pollinators are most likely to show up and time their pollen production accordingly. A plant's form is a record of its history. Its cells—shaped by experience—remember.

Chat? Anticipate? Remember? It's tempting to tame all those words with scare quotes, as if they can't mean for plants what they mean for us. For plants, we say, it's biochemistry, just physiology and brute mechanics—as if that's not true for us, too.

Besides, Calvo says, plant behavior can't be reduced to mere reflexes. Plants don't react to stimuli in predetermined ways—they'd never have made it this far, evolutionarily speaking, if they did. Having to deal with a changing environment while being rooted to one spot means having to set priorities, strike compromises, change course on the fly.

Consider stomata: tiny pores on the undersides of leaves. When the pores are open, carbon dioxide floods in—that's good, that's breathing—but water vapor can escape. So how open should the stomata be at any given time? It depends on the availability of water in the soil—if there's plenty more for the taking, it's worth letting the carbon dioxide in. If the dirt's dry, the leaves have to retain water. For the leaves to make that decision, the roots have to tell them about the availability of water. The leaves communicate their own needs to the roots in turn, encouraging them, for example, to form symbiotic relationships with specific microorganisms in the soil.[3]

If a plant could respond to sensory information on a one-to-one basis—when the light does *x*, the plant does *y*—it would be fair to think of plants as mere automatons, operating without thought, without a point of view. But in real life, that's never the case. Like all organisms, plants are immersed in dynamic, precarious environments, forced to confront problems with no clear solutions, betting their lives as they go. "A biological system is never exposed to just a single source of stimulation," Calvo says. "It always has to make a compromise among different things. It needs some kind of valence, a higher-level perspective. And that's the entry to sentience."

Sentience?

Are plants clever? Maybe. Adaptive? Sure. But sentient? Aware? *Conscious*? Listen closely and you can hear the scoffing.

To feel alive, to have a subjective experience of your surroundings, to be an organism whose lights are on and someone's home—that's reserved for creatures with brains, or so says traditional cognitive science. Only brains, the theory goes, can encode mental representations, models *of* the world that brains experience *as* the world. As Jon Mallatt, a biologist the University of Washington, and colleagues put it in their 2021 critique of Calvo's work, "Debunking a Myth: Plant Consciousness," to be conscious requires "experiencing a mental image or representation of the sensed world," which brainless plants have no means of doing.[4]

But for Calvo, that's exactly the point. If the representational theory of the mind says that plants can't perform intelligent, cognitive behaviors, and

the evidence shows that plants *do* perform intelligent, cognitive behaviors, maybe it's time to rethink the theory. "We have plants doing amazing things and they have no neurons," he says. "So maybe we should question the very premise that neurons are needed for cognition at all."

THE IDEA THAT THE MIND is in the brain comes to us from Descartes. The 17th-century philosopher invented our modern notion of consciousness and confined it to the interior of the skull. He saw the mind and brain as separate substances, but with no direct access to the world. The mind was reliant on the brain to encode and represent the world or conjure up its best guess as to what the world might be based on, with ambiguous clues trickling in through unreliable senses. What Descartes called "cerebral impressions" are today's "mental representations." As cognitive scientist Ezequiel Di Paolo writes, "Western philosophical tradition since Descartes has been haunted by a pervasive mediational epistemology: the widespread assumption that one cannot have knowledge of what is *outside* oneself except through the ideas one has *inside* oneself."[5]

The mind isn't the brain. It's the body's engagement with the world.

Modern cognitive science traded Descartes' mind-body dualism for brain-body dualism: The body is necessary for breathing, eating, and staying alive, but it's the brain alone, in its dark, silent sanctuary, that perceives, feels, and thinks. The idea that consciousness is *in* the brain is so ingrained in our science, in our everyday speech, even in popular culture that it seems almost beyond question. "We just don't even notice that we are adopting a view that is still a hypothesis," says Louise Barrett, a biologist at the University of Lethbridge in Canada who studies cognition in humans and other primates.

Barrett, like Calvo, is one of an increasing number of scientists and philosophers questioning that hypothesis because it doesn't comport with a biological understanding of living organisms. "We need to get away from thinking of ourselves as machines," Barrett says. "That metaphor is getting in the way of understanding living, wild cognition."

Instead, Barrett and Calvo draw from a set of ideas referred to as "4E cognitive science," an umbrella term for a bunch of theories that all happen to start with the letter "E." Embodied, embedded, extended, and enactive cognition—what they have in common (besides "E"s) is a rejection of cognition as a purely brainbound affair. Calvo is also inspired by a fifth "E": ecological psychology, a kindred spirit to the canonical four. It's a theory of how we perceive without using internal representations.

In the standard story of how vision works, it's the brain that does the heavy lifting of creating a visual scene. It has to, the story goes, because the eyes contribute so little information. In a given visual fixation, the pattern of light in focus on the retina amounts to a two-dimensional area the size of a thumbnail

at arm's length. And yet we have the impression of being immersed in a rich three-dimensional scene. So it must be that the brain "fills in" the missing pieces, making inferences from scant data and offering up its best hallucination for who-knows-who to "see," who-knows-how.

Dating back to the work of psychologist James Gibson in the 1960s, ecological psychology offers a different story. In real life, it says, we never deal with static images. Our eyes are always moving, darting back and forth in tiny bursts called saccades so quick we don't even notice. Our heads move, too, as do our bodies through space, so what we're confronted with is never a fixed pattern of light but what Gibson called an "optic flow."

To "see," according to ecological psychology, is not to form a picture of the world in your head. It stresses that patterns of light on the retina change relative to your movements. It's not the brain that sees, but the whole animate body. The result of "seeing" is never a final image for an internal mind to contemplate in its secret lair, but an adaptive, ongoing engagement with the world.

Plants don't have eyes exactly, but flows of light and energy impinge on their senses and transform in predictable ways relative to the plants' own movements. Of course, to notice that, you first have to notice that plants move.

"If you think that plants are sessile," or stationary, Calvo says, "just sitting there, taking life as it comes, it's difficult to visualize the idea that they are generating these flows."

Plants appear sessile to us only because they move slowly. Quick movements—like the nightly shuffle of my prayer plant—can be accomplished by altering the water content in certain cells to change the tension in a stem, or to stiffen a branch under the weight of heavy snow. Most plant movement, though, occurs through growth. Since they can't pick up their roots and walk away, plants change location by growing in a new direction. We humans are basically stuck with the shape of our bodies, but at least we can move around; plants can't move around, but they can grow into whatever shape best suits them. This "phenotypic plasticity," as it's called, is why it's critical for plants to be able to plan ahead.

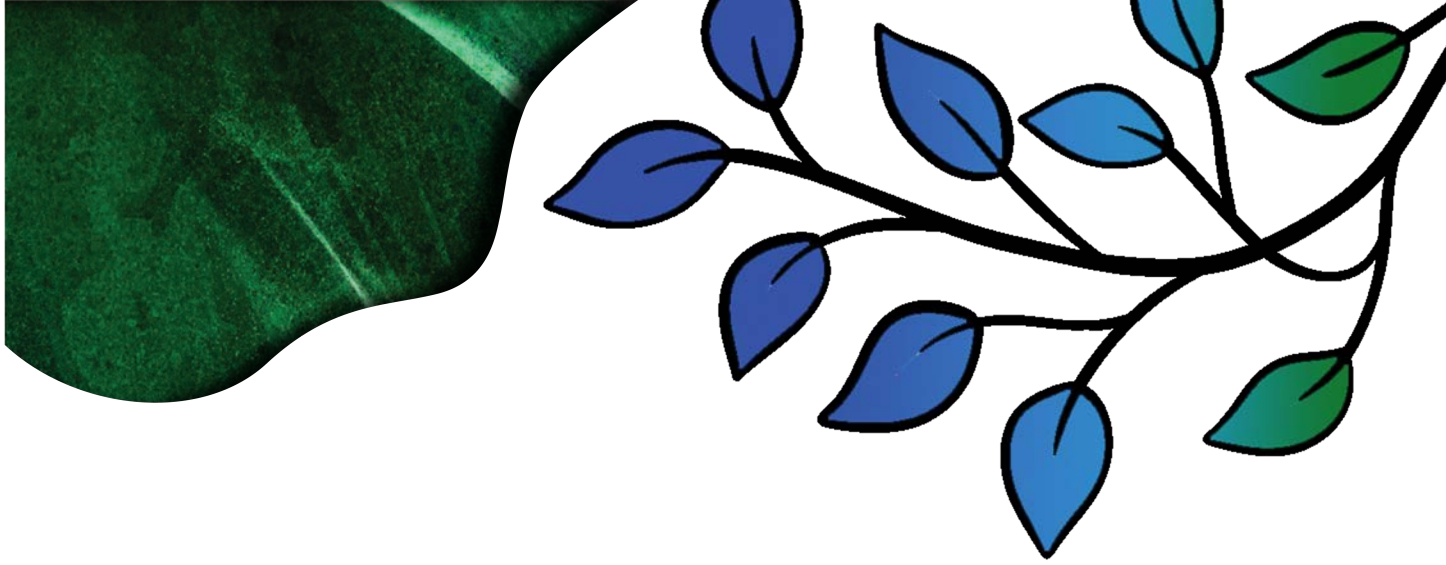
"If you spend all this time growing a tendril in a particular direction," Barrett says, "you can't afford to get it wrong. That's why prediction does seem very important. It's like my granddad said; maybe all granddads say this: 'measure twice, cut once.' "

Phenotypic plasticity is a powerful but slow process—to see it, you have to speed it up. So Calvo makes time-lapse recordings, in which slow and seemingly random growth blooms into what appears to be purposeful behavior. One of his time-lapse videos shows a climbing bean growing in search of a pole. The vine circles aimlessly as it grows. Hours are compressed into minutes. But when the plant senses a pole, everything changes: It pulls itself back, like a fisherman casting a line, then flings itself straight for the pole and makes a grab.

"Once movement becomes conspicuous by speeding it up," Calvo says, "you see that certainly plants are generating flows with their movement."

By using these flows to guide their movements, plants accomplish all kinds of feats, such as "shade avoidance"—steering clear of over-populated areas where there's too much competition for photosynthesis. Plants, Calvo explains, absorb red light but reflect far-red light. As a plant grows in a given direction, it can watch how the ratio of red to far-red light varies and change directions if it finds itself heading for a crowd.

"They are not storing an image of their surroundings to make computations," Calvo says. "They're not making a map of the vicinity and plotting where the



competition is and then deciding to grow the other way. They just use the environment around them."

That might seem to be a long cry from how humans perceive the world—but according to 4E cognition, the same principles apply. Humans don't perceive the world by forming internal images either. Perception, for the E's, is a form of sensorimotor coordination. We learn the sensory consequences of our movements, which in turn shapes how we move.

Just watch an outfielder catch a fly ball.[6] Standard cognitive science would say the athlete's brain computes the ball's projectile motion and predicts where it's going to land. Then the brain tells the body what to do, the mere output of a cognitive process that took place entirely inside the head. If all that were true, the player could just make a beeline to that spot—running in a straight line, no need to watch the ball—and catch.

But that's not what outfielders do. Instead, they move their bodies, constantly shuffling back and forth and watching how the position of the ball changes as they move. They do this because if they can keep the ball's speed steady in their field of vision—canceling out the ball's acceleration with their own—they and the ball will end up in the same spot. The player doesn't have to solve differential equations on a mental model—the movement of her body relative to the ball solves the problem for her in active engagement, in real time. As the MIT roboticist Rodney Brooks wrote in a landmark 1991 paper, "Intelligence Without Representation," "Explicit representations and models of the world simply get in the way. It turns out to be better to use the world as its own model."[7]

If cognition is embodied, extended, embedded, enactive, and ecological, then what we call the mind is not in the brain. It is the body's active engagement with the world, made not of neural firings alone but of sensorimotor loops that run through the brain, body, and environment. In other words, the mind is not in the head. Calvo likes to quote the psychologist William Mace: "Ask not what's inside your head, but what your head's inside of."

WHEN I FIRST ENCOUNTERED the 4E theories, I couldn't help thinking of consciousness. If the mind is embodied, extended, embedded, etcetera, does consciousness—that magical, misty stuff—seep out of the confines of the skull, permeate the body, pour like smoke from the ears, and leak out into the world? But then I realized that way of thinking was a hangover from the traditional view, where consciousness was treated as a noun, as something that could be located in a particular place.

"Cognition is not something that plants—or indeed animals—can possibly *have*," Calvo writes in his new book, *Planta Sapiens*. "It is rather something created by the interaction between an organism and its environment. Don't think of what's going on inside the organism, but rather how the organism *couples* to its surroundings, for that is where experience is created."

The mind, in that sense, is better understood as a verb. As the philosopher Alva Noë, who works in embodied cognition, puts it, "Consciousness isn't something that happens inside us: It is something we do."[8]

And we do it in order to keep on living. The need to stay alive, to tread in far-from-equilibrium water—*that* is what separates us from machines. "Wild cognition," as Barrett puts it, is more akin to a candle flame than to a computer. "We are ongoing processes resisting the second law of thermodynamics," she says. We are candles desperately working to re-light ourselves, while entropy does its damnedest to blow us out. Machines are made—one and done—but living things make themselves, and they have to remake themselves so long as they want to keep living.

The Chilean biologists Humberto Maturana and Francisco Varela—founding fathers of embodied and enactive cognition—coined the term "autopoiesis" to capture this property of self-creation. A cell—the fundamental unit of life—serves as the prime example.

Cells consist of metabolic networks that churn out the very components of those networks, including the cell membrane, which the network continuously builds and rebuilds, while the membrane, in turn, allows the network to function without oozing back into the world. To keep its metabolism going, the cell needs to be in constant exchange with its environment, drawing in resources and tossing out waste, which means the membrane has to let things pass through it. But it can't do it indiscriminately. The cell has to take a stance on the world, to view it as a place of value, full of things that are "good" and "bad," "useful" and "harmful," where such terms are never absolute but dependent on the cell's ever-changing needs and the environment's ever-changing dynamics.

These valences, Calvo says, are the stirrings of sentience. They are distinctions that carve out (or "enact") a world in a process that 4E cognitive scientists call "sense-making." The act of making valenced distinctions in the world, which allow you to draw the boundary between self and other, is the primordial cognitive act from which all higher levels of cognition ultimately derive. The same act that keeps a living system living is the act by which, as Noë puts it, "the world shows up for us."

"You start with life," says Evan Thompson, a philosopher at the University of British Columbia and one of the founders of the enactive approach. "Being alive means being organized in a certain way. You're organized to have a certain autonomy, and that immediately carves out a world or a domain of relevance." Thompson calls this "life-mind continuity." Or as Calvo puts it, echoing the 19th-century psychologist Wilhelm Wundt, "Where there is life there is already mind."

From a 4E perspective, minds come before brains. Brains come into the picture when you have multicellular, mobile organisms—not to represent the world or give rise to consciousness, but to forge connections between sensory and motor systems so that the organism can act as a singular whole and move through its environment in ways that keep its flame lit.

"The brain fundamentally is a life regulation organ," Thompson says. "In that sense, it's like the heart or the kidney. When you have animal life, it's crucially dependent for the regulation of the body, its maintenance, and all its behavioral capacities. The brain is facilitating what the organism does. Words like cognition, memory, attention, or consciousness—those words for me are

We should question whether neurons are needed for cognition at all.

properly applied to the whole organism. It's the whole organism that's conscious, not the brain that's conscious. It's the whole organism that attends or remembers. The brain makes animal cognition possible, it facilitates and enables it, but it's not the *location* of it."

A bird needs wings to fly, Thompson says, but the flight is not *in* the wings. Disembodied wings in a vat could never fly—it's the whole bird, in interaction with the air currents shaped by its own movements, that takes to the sky.

"Plants are a different strategy of multicellularity than animals," Thompson says. They don't have brains, but according to Calvo they have something just as good: complex vascular systems, with networks of connections arranged in layers not unlike a mammalian cortex. In the root apex—a small region in the tip of a plant's root—sensory and motor signals are integrated through electrochemical activity using molecules similar to the neurotransmitters in our brains, with plant cells firing off action potentials similar to a neuron's, only slower. Like the human brain, the root apex allows the plant to integrate all of its sensory flows in order to produce new behavior that will generate new flows in ways that keep the plant adaptively coupled to the world.

The similar roles played by an animal's nervous system and a plant's vascular system help explain why the same anesthetics can put both animals and plants to sleep, as Calvo demonstrated using a Venus flytrap in a bell jar. Normally, the plant's traps snap shut when an unfortunate insect triggers one of its sensor hairs, which protrude from the trap's mouth like sharks' teeth. (Actually, the clever plant awaits the triggering of a second hair within seconds of the first before expending the costly energy to bite. Once closed, it awaits three more triggers—to ensure there's a decent bug buzzing around in there—before it releases acidic enzymes to digest its meal. As Calvo sums it up, "They can count to five!") Using surface electrodes, Calvo watched as the triggered hairs sent electric spikes zapping through the plant, sparking its motor system to react. With anesthesia, all of that stopped. Calvo tickled the trap's hairs and it just sat there, its mouth agape. The electrode reading flatlined.

"The anesthesia prevents the cell from firing an action potential," Calvo explains. "That happens in both plants and animals." It's not that the anesthetic is turning down the dial of consciousness inside the brain or root apex, it's just severing the links between sensory inputs and motor outputs, preventing the organism from engaging as a singular whole with its environment. Once "woken," though, the groggy Venus flytraps quickly returned to their usual behavior.

"Clearly," Thompson says, "plants are self-organizing, self-maintaining, self-regulating, highly adaptive, they engage in complex signaling among each other, within species and across species, and they do that within a framework of multicellularity that's different from animal life but exhibits all the same things: autonomy, intelligence, adaptivity, sense-making." From a 4E perspective, Thompson says, "there's no problem in talking about plant cognition."

In the end, Calvo's critics are right: Plants aren't using brains to form internal representations. They have no private, conscious worlds locked up inside them. But according to 4E cognitive science, neither do we.

"The mistake was to think that cognition was in the head," Calvo says. "It belongs to the relationship between the organism and its environment."

AFTER TALKING WITH CALVO, I looked around my apartment overrun with plants—at the pothos and bromeliads, rocktrumpet vines and staghorn ferns, at the peace lilies and crowns of thorns, snake plants, Monstera, ZZs, and palms—and they suddenly appeared very different. For one thing, Calvo had told me to think of plants as being upside-down, with their "heads" plunged into the soil and their limbs and sex organs sticking up and flailing around. Once you look at a plant that way, it's hard to unsee it. But more to the point, the plants appeared to me now not as objects, but as subjects—as living, striving beings trying to make it in the world—and I found myself wondering whether they felt lonely in their pots, or panicked when I forgot to water them, or dizzy when I rotated them on the windowsill.

It wasn't just the plants. I felt myself differently, too: less like a passive spectator, snug inside my skull, and more like an active life form, tendrilled and strange, moving through the world as the world moved through me.

"Plants are not that different from us after all," Calvo had told me, "not because I'm beefing them up to make them more similar to us, but because I'm rethinking what human perception is about. I'm neither inflating them nor deflating us but putting us all on the same page."

It was hard not to wonder whether, from that page, the story of our planet might unfold differently. The "E" approaches ask us to question what we are, how intimately we're entangled with the world, and whether we can rightly see ourselves as standing apart from nature or whether the destruction we wreak is steadily diminishing our own wild cognition.

"Human nature," wrote John Dewey, the pragmatist philosopher, "exists and operates in an environment. And it is not 'in' that environment as coins are in a box, but as a plant is in the sunlight and soil. It is of them."[9]

AMANDA GEFTER is a science writer and author of *Trespassing on Einstein's Lawn*. She lives in Watertown, Massachusetts.

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LISTEN TO THE OCEAN
"We are inhabitants of an ocean world. Everything that happens down there is linked to us up here."
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The Universal Clock of Aging

Father Time is ticking away in our DNA

BY ELENA KAZAMIA

WHEN GERTRUDE STEIN famously quipped that "we are always the same age inside," she certainly wasn't referring to the conglomerate of cells, carefully organized into tissues, that form a human body. We all understand that despite our best efforts to preserve youth, our material bodies inevitably age and fail us. Yet trying to understand whether all our body's cells age at the same rate is not a trivial question in biology. Some of our tissues are built to last and degenerate slowly, like the soft spongy tissues that form the brain, while others, like a red blood cell, have a much shorter lifespan. It's long been a central tenet of biology that aging results from the random accumulation of damage to specific cells over time.

But in the past decade, Steve Horvath, while a professor in human genetics and biostatistics at the University of California, Los Angeles, honed the thesis that aging in every tissue can be predicted by a single mathematical formula. In a 2022 paper, Horvath, together with an international group of scientists, identified this formula in 185 mammalian species.[1] "I think it's unbelievable that this is even possible," Horvath told me. "But one formula can measure age in all species and all tissues."

The formula implies that there is a universal clock to aging. As the years tick by, the risk of mortality increases. Tissues degenerate by accumulating wear and tear in the form of molecular damage, while the aging program depletes the body's reserves of young stem cells to replace them. Some see this as evolution, a cruel mistress, having programmed us to die. But to Horvath, aging is unintentional. "I don't want to say evolution selected a program that makes us die. I think it's just that Mother Nature never selected against it," he says.

If you have empathy for Dorian Gray, Oscar Wilde's infamous protagonist who bartered his soul to not "grow old, and horrible, and dreadful," you will agree this is a highly lamentable oversight. "Essentially, the program serves the purpose of development, perhaps protection against malignant transformation, and then later in life it does something bad," Horvath says. Borrowing a phrase from João Pedro de Magalhães, an aging researcher at the University of Birmingham, he adds, "Aging is a coding error in the system." Horvath sees this error as an emergent property, the result of cumulative subtle changes in cell identity and tissue composition, which together gradually compromise fitness and lead to a decline of organ function and the manifestation of physical aging.

If aging is a coding error in the system, can it be fixed?

Horvath is now synonymous with the term "biological age," a tantalizing metric that refers to the youthfulness of individuals rather than their "chronological age," as measured from the time of their birth. Markers of biological age can be interpreted as predictors of mortality. The hunt for accurate markers is a longstanding pursuit in the medical field and has included quantitative measurements, such as blood serum analyses of specific proteins or metabolites, as well as composite indices based on the more qualitative measurements of frailty and cognitive function. Most recently, scientists have looked to changes in DNA as the harbingers of aging. Reliable markers of biological age can reveal more about how those of us with an "accelerated" biological clock are aging too quickly. It's not surprising that known factors that speed the process include lifestyle habits such as smoking and overeating.

Horvath's "clock" has allowed scientists to "truly quantify aging," says Vadim Gladyshev, a professor of medicine at Brigham and Women's Hospital, Harvard Medical School, whose own research focuses on understanding the causative biological processes behind aging. "It was revolutionary. If you think about what was available to us 10 years ago, scientists were not able to quantify aging on the molecular level. They would quantify protein accumulation or telomere length or some kind of other functional feature,

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but these are individual measurements that are not really accurate. It was clear that the quantification was just not good enough, so you couldn't draw many conclusions. When Steve developed the first clock, that's when I knew this was the future. We followed in his steps."

A mathematician by training, Horvath published his first clock theory in 2011, using an analysis of saliva samples collected from a study of twins, intended to shed light onto the origins of homosexuality. Horvath was part of the study along with his brother, with whom he shares an identical genome but different sexual orientation. The study collected information on the entire genome sequences of the participants, the expression patterns of all genes, and whether the DNA material had accumulated physical "epigenetic" changes, in other words, a sea of information. "We were a data point," Horvath told me.

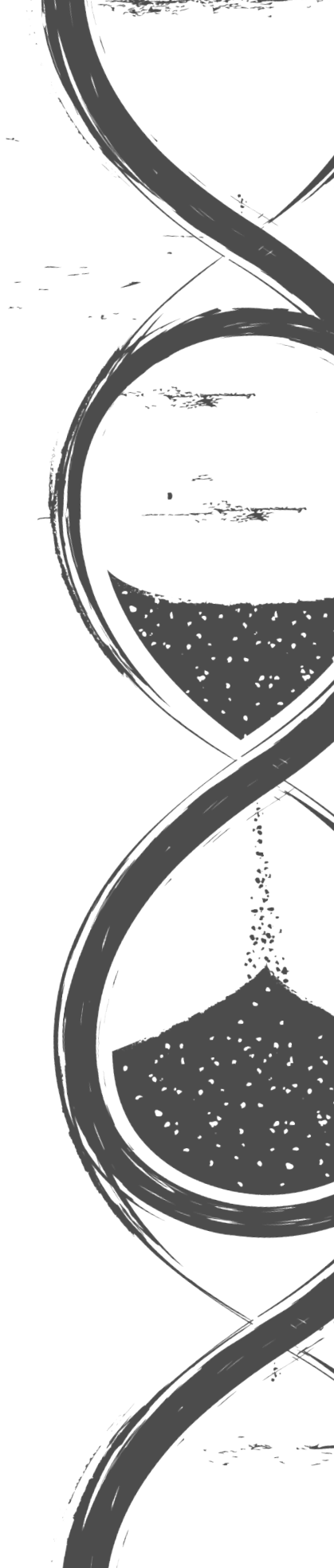
Without a penny of funding to invest in studying the possible biological predispositions for homosexuality, Horvath spent countless hours on weekends and in his free time analyzing the wealth of data from the study, motivated by a personal curiosity. But instead of finding a plausible causal link for sexual orientation, his statistical analyses found a startling correlation between certain physical modifications to the saliva's DNA and the age of the study's participants. "Honestly, the signal was so strong, you could use any statistical model and you would see it," he told me. Nevertheless, the result was unexpected because no one was looking at the relationship between epigenetics and age, and his findings kicked off further investigations.

Epigenetics is the study of physical modifications to our genes that either prevent or enhance their expression. What Horvath was able to observe by narrowing in mathematically on 80 or so genes across the whole human genome, a mere sprinkling of the 20,000, was that the presence or absence of epigenetic marks significantly correlated with the chronological age of the 34 twin pairs from the study.[2] The physical marks on the genes, specifically methylations to cytosines (the process by which a small chemical tag, a methyl group, is added to one of the four DNA bases that are used in the encryption of the genetic code), were the equivalent of molecular wrinkles. Horvath had cleverly

FORMULA ONE "I think it's unbelievable that this is even possible. But one formula can measure age in all species and all tissues," Steve Horvath says.

NICHOLAS BARRETT PHOTOGRAPHY

Evolution is a cruel mistress, having programmed us to die.



come up with a statistical model that could be used to count them and date individuals. He called the formula, which calculates the epigenetic marks on the relevant genes, a methylation (or epigenetic) clock for estimating the age of a tissue sample. The result was striking, and the very first epigenetic clock could estimate the age of individuals within an accuracy of 5.2 years.

The advancement of clock theories represented a movement from simple correlation to a causal link between epigenetics and aging. A breakthrough in understanding came from Horvath's discovery of the "pan-tissue clock." This is the set of methylation markers that predict the biological age of an individual, not just in one type of tissue, such as saliva from the original study, but in all the various tissues that comprise an organism.

"When I developed the pan-tissue clock, that really garnered the attention of the aging community," Horvath says. "A pan-tissue clock was paradoxical because methylation is supposed to control cell identity," and remains fixed through adulthood. When Horvath and his colleagues established that epigenetic clocks counted time at the same pace across all tissues, whether that was quickly dividing blood cells or notoriously slow and highly differentiated brain neurons, the race was on to understand the fabric of time that the clocks are measuring. The universal clock, the key finding of Horvath's 2022 paper, takes the pan-tissue clock one step further. It chimed the final stroke that unequivocally showed a predictable pattern to aging not only within the body of a single organism, but across mammals.

Horvath is excited about the "vampire idea" of anti-aging.

One big question that arises from Horvath's research is whether DNA wrinkles are the cause or the effect of aging. Could they simply be akin to cosmetic changes to the body that bear no consequence on the ultimate outcome? After all, a clock simply measures time, it isn't its driver.

"It is the critical question," Horvath says. "The discussion we have today pertains to fourth-generation clocks. These are clocks that hopefully are comprised of cytosines that truly have a causative role in the aging process. But we are not there yet. We have some understanding that cytosines may play a causal role," he stressed. Of particular interest are "enhancer" regions of the genome, which exaggerate the role of certain genes by activating them to exorbitant levels. A recent study of Alzheimer's disease, for example, found that methylation losses in specific enhancer regions occur in normal aging neurons, but are accelerated in patients with the disease.[3]

Then there's the billion-dollar question. If aging, as Horvath said, is a coding error, can it be fixed? Just now, Horvath is excited about an avenue of research he calls the "vampire idea." In a recent paper, Horvath and colleagues presented the results of a clinical trial in which concentrated

umbilical cord plasma was injected into 18 audacious senior volunteers (60 to 95 years old), all deemed to be of "normal health for their ages."[4] The researchers measured the effect of the plasma treatment on the subjects' aptly named GrimAge clock, an epigenetic predictor of "time to death" in humans.[5] As part of the trial, participants were injected with 100ml of concentrated umbilical cord plasma, blood that is collected and processed at the time of a baby's birth, on a weekly basis for a total of 10 weeks. "Sure enough, GrimAge showed that the umbilical cord plasma rejuvenated the participants—by a small amount, but it was statistically significant," Horvath says. Earlier studies had shown that transfusing young blood can dramatically reenergize elderly rats. "We found that when a young mouse had coupled circulation to an older mouse, the old mouse becomes younger and lives longer—it is a very striking result," says Gladyshev.

Horvath recently left academia to join a biotechnology startup, Altos Labs, launched in 2022 with $3 billion in investments. Aging, he says, is accompanied by a breakdown of resilience in cells. COVID-19 is the most salient recent example. The virus affects the elderly more drastically because their cells lack the resiliency to fight back. The opportunity to focus on improving "cellular health and boosting resilience," Horvath says, was the next logical step.

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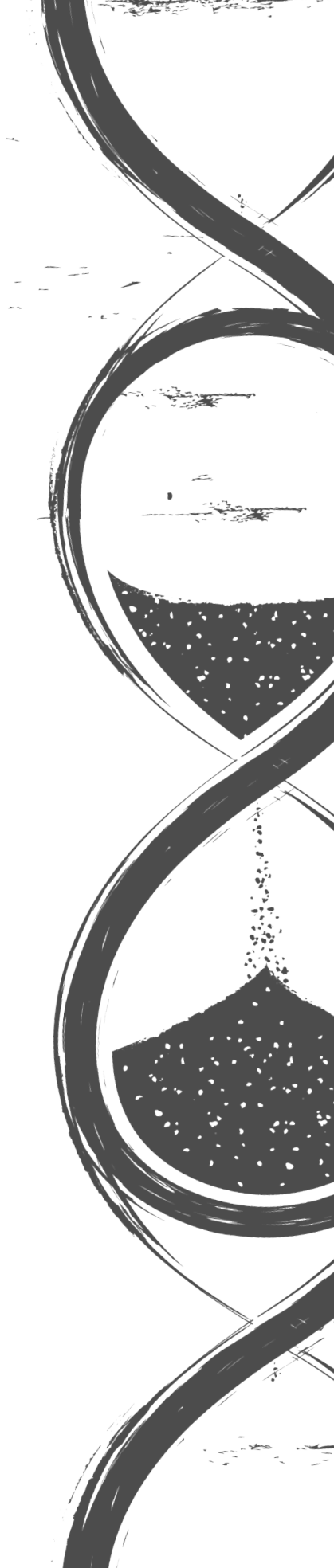
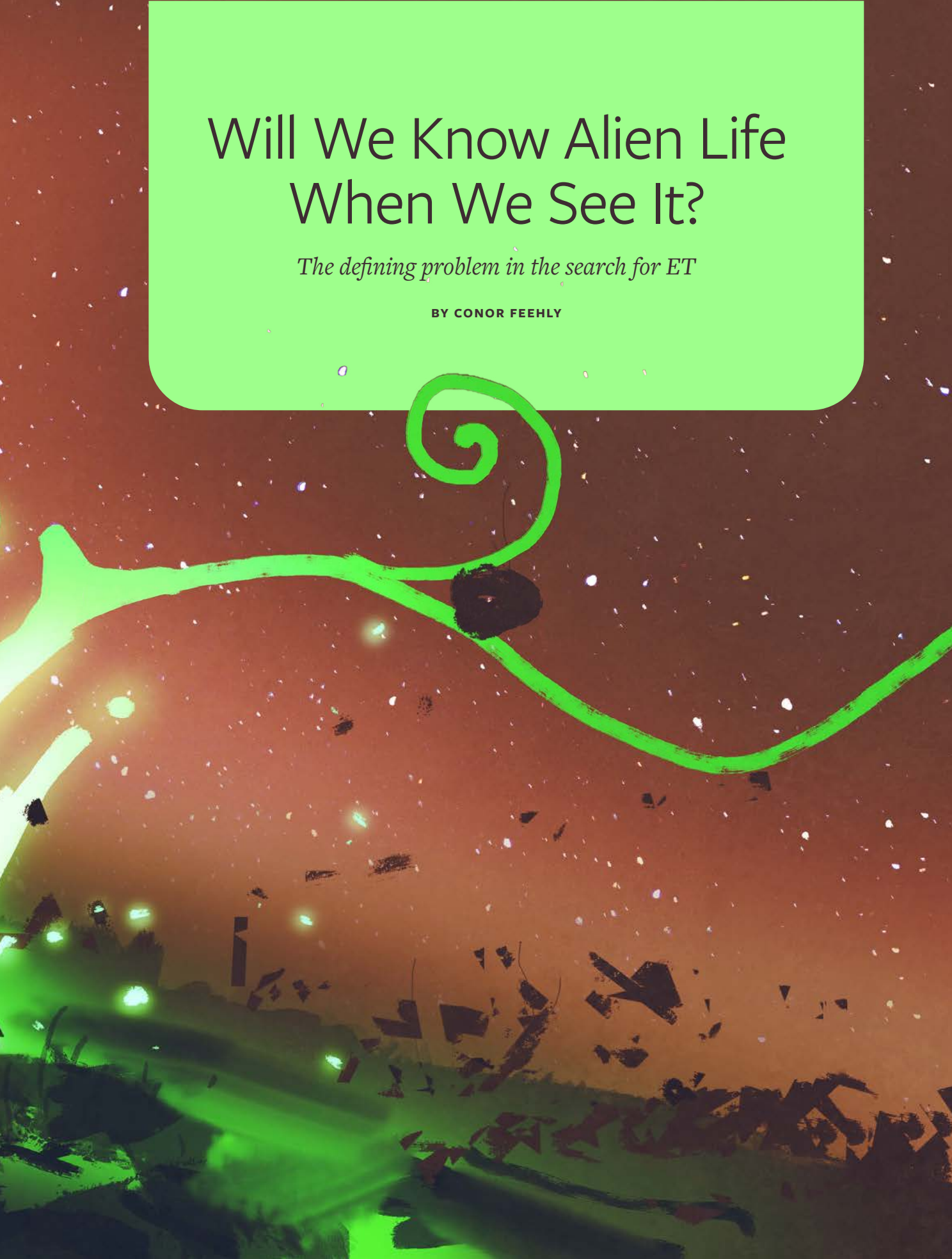


Will We Know Alien Life When We See It?

The defining problem in the search for ET

BY CONOR FEEHLY



IN THE 1958 SCIENCE-FICTION MOVIE *The Blob*, an amorphous alien hitchhiked a ride to Earth on a meteorite. Upon landing, the translucent extraterrestrial began to devour humans, growing larger and redder with each meal. While the amoeba-like alien in the cult classic was famous for its insatiable hunger, *The Blob* managed to articulate something that previous science-fiction movies hadn't: There's no guarantee aliens will look anything like the lifeforms that we are familiar with.

Scientists and philosophers have been attempting to define life for ages. In biology class we were taught to define life through the set of features that we, and every other species on the planet share. Things like movement, respiration, growth, and reproduction. Life is made of cells and has DNA. But does biochemistry constitute the whole picture? As far back as 1970, Carl Sagan didn't think so. Attempts at defining life, he and many others thought, were too constrained by the characteristics of life as we know it. A single example of extraterrestrial life could change everything.

Employing an elegant music metaphor, Sagan wrote, "It is not known whether there is a vast array of biological themes and counterpoints in the universe; whether there are places that have fugues, compared with which our one tune is a bit thin and reedy. Or it may be that our tune is the only tune around. Accordingly, the prospects for life on other planets must be considered in any general discussion of life."

Today a new generation of astrobiologists have taken Sagan's prospect to heart. If life has managed to gain a foothold somewhere else in the cosmos, alien life could look very different than the varieties of life found on Earth. If we don't have a broad, robust definition of what life is, we may miss it when searching for extraterrestrial life in the cosmos.

In a white paper submitted to the Planetary Science and Astrobiology Decadal Survey 2023-2032, of the National Academies, a group of scientists affiliated with NASA, SETI, and universities around the world, outlined a way forward in astrobiological research. They wrote "the probability that life in the universe would share a biochemical ancestry with life on Earth quickly diminishes the further away from Earth we explore." It's imperative, the scientists continued, "that we build foundational knowledge for life detection strategies that target universal biosignatures."

Aaron Goldman, a biologist from Oberlin College, who has been working on problems relating to the origin of life on Earth, says it's important we distinguish what we mean when we talk about living and non-living entities, especially in the context of astrobiology. "The most successful definitions of life fall into two general categories: entropic definitions, which describe life through its ability to increase internal order at the expense of increasing disorder in the surrounding environment; and evolutionary definitions, which describe life through its ability to evolve by natural selection," Goldman says.

Entropic definitions detail life's ability to harness sources of free energy, such as the sun, that feed metabolic processes which allow life to build structures and carry out its functions. The set of objects we call "life" are highly ordered and are low in entropy, according to this view.

But the entropic view of life is not without its problems. A counterintuitive result of thinking about life this way means stars themselves could meet

PAGES 40-41: TITHI LUADTHONG / SHUTTERSTOCK

the criteria to be considered life. Nuclear fusion and fission in the star's core maintain the structures and processes that are necessary to its stable physiology and anatomy—a type of stellar metabolism that mirrors the metabolic processes of biological organisms. It seems obvious, though, that stars are not living, or at least they are not in the same class of entities that we might call life. Similarly, it's easy to see the appeal of evolutionary definitions of life as a self-sustaining system capable of Darwinian evolution. Evolution by natural selection has driven diversity and adaptation in all living things on Earth since the last universal common ancestor.

Stars themselves could meet the criteria to be considered life.

The trouble with qualitative descriptions of life, like the entropic and evolutionary approaches, is they often present numerous gray areas and strange counter examples. In such cases we are left with a set of life's features that serve as a litmus test for whether one set of phenomena qualifies as life or not. Are viruses alive? Being unable to replicate without infecting a host, and their lack of energy needs, might suggest they aren't under both the entropic and evolutionary views. What about digital or synthetic lifeforms? A lot of people might say no because they don't share the biological features with the entities that we do call living, and are composed of an entirely different substrate. Under one such set of criteria, our answers might say no, and under another they might say yes, while our intuition might tell us something else altogether.

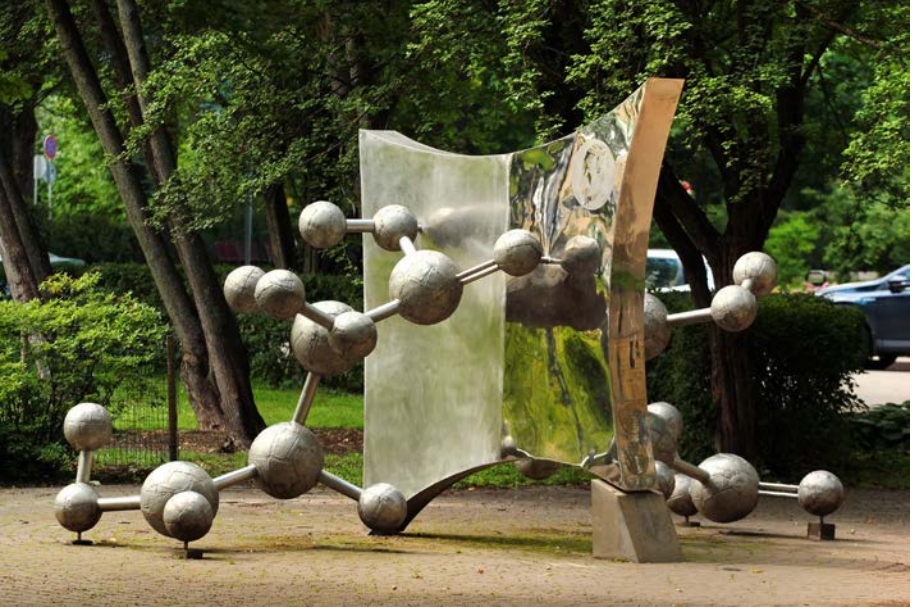
In recognizing the problems that can crop up when trying to apply these universal qualitative definitions of life, astrobiologists have asked, Are there quantifiable features of chemistry that can distinguish the characteristics of life in a way that can be applied in our search for extraterrestrial life? Could it be possible to build a "physics of life" from the ground up?

ONE OF THE FIRST ATTEMPTS at setting out a quantifiable framework for identifying extraterrestrial biological processes was made in 2004 by NASA planetary scientist Chris McKay. McKay introduced the "lego principle," which describes the blocks of molecules that constitute structures in biology, such as proteins. McKay noticed that in contrast to abiotic processes, biology does not draw from the full range of available organic molecules when producing structures associated with life. Amino acids, which are probably the most important set of organic molecules used in Earth-based living systems, have the quality of being chiral. This means they have a non-superimposable mirror image, or that each amino acid has a left-handed and a right-handed version of itself. Of the 20 amino acids used in proteins, Earth-based life only makes use of the left-handed version, whereas abiotic processes tend to use an even distribution of left-handed and right-handed organic molecules.

McKay's lego principle could be applied in the search for alien biochemistry in the solar system. Organic material sampled from promising sites for life, like Mars or Europa, could be tested for the chirality of one type of organic molecule over the other. Analyzing the concentration of organic molecules in these environments may reveal patterns indicative of life, even if those patterns do not involve the specific organic molecules exploited by Earth-based life.

Astrobiologist Sara Walker from Arizona State University and chemist Lee Cronin from the University of Glasgow have their own view of life. Their "assembly theory" suggests there is a quantifiable difference in the complexity of molecules that can be created by living processes compared to non-living ones. "Basically the idea is what underlies life is the physics that builds complexity in the universe," Walker says.

In a rudimentary way, for an atom to form a bond to create a molecule, an energy barrier has to be crossed, so as a molecule gets more complex, it gets increasingly unlikely that it was created by chance; or as Walker puts it, "the universe doesn't make complex things for free." Life, though, is able to bypass these energy barriers, opening up an extremely vast chemical space where a mind-boggling number of complex molecular structures can be realized. The goal of assembly theory, says Walker, is to "understand the circumstances when selection emerges and when you start building up complexity."



MIRROR, MIRROR Amino acids, key to Earth-based life, are chiral, meaning they have a non-superimposable mirror image, or that each amino acid has a left-handed and a right-handed version of itself.

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Could it be possible to build a "physics of life" from the ground up?

Assembly theory describes complex molecules with something called the molecular assembly index. The molecular assembly value of a molecule is determined by the shortest number of steps that are needed to create that molecule through its elementary building blocks (atoms and their bonds), and this number can be derived for a given molecule through analysis in mass spectrometers. Finding collections of molecules in space above a certain molecular assembly threshold would highly suggest the presence of processes that we might call living. For assembly theory, it is the intrinsic complexity of an object which determines whether it was the product of living processes.

"The perspective I have is that what we really need to do is not start from definitions of life and use those as guiding principles, but to try to start from thinking about the origin of life and what it means when life arises in a system," Walker says. "What is fundamentally different when we talk about the general category of life and non-living things in the universe, and what sort of laws or principles would allow us to talk about that whole category and when that transition happens?"

Imagine human astronauts scouring the surface of distant planets for signs of life. They come across an object that is undoubtedly a piece of alien technology. As a highly ordered and complex structure, we could not assume that it had randomly appeared into existence by chance. To properly explain its existence, we would have to tell a multibillion-year-long story, explaining how geochemical cycles on the planet evolved into life, which then evolved into intelligent life that eventually developed technology which was capable of building the alien hardware. "Cell phones don't randomly fluctuate out of a vacuum," quips Walker.

This example illustrates that the more complex a structure becomes, whether it is a piece of elaborate technology or even a molecule, the less likely it is that structure appeared by chance. Instead, a process which can use information to build complex structures has to be responsible for the creation of such complexity, and Walker and Cronin call that process life. Human technology and any potential alien technology is an extension of living processes and are part of the same lineage of complex objects.

The difference between what assembly theory calls living processes and non-living processes is that living processes are governed by information conserved through a history of interactions between an entity and its environment, whereas non-living processes are largely determined by chance. The mechanism for recording the history of interactions in the living entities we are familiar with is DNA, but that mechanism could look different in other varieties of life.

"The universe doesn't make complex things for free."

The main hurdle for applying assembly theory in trying to identify extraterrestrial life is that, at least currently, measurements must be made in situ, or on site. While NASA has plans to send mass spectrometers to Titan and Europa in the hope of identifying living chemistry, Walker thinks they will not have the high-resolution capacity to make the measurements that assembly theory would require. We are limited with how far we can send our instruments now, and there's a big universe out there with lots of possible locations for life. Walker notes, however, that researchers working on assembly theory are developing ways the framework can be applied in the spectrographic analysis of exoplanet atmospheres.

ONE OF THE MOST TALKED-ABOUT methods that scientists will use for life detection is to look for atmospheric biosignatures, or chemical byproducts of living processes in the atmospheres of alien worlds. Life on Earth is responsible for a lot of what makes up our atmosphere, and by analyzing the atmospheres of planets outside our solar system, scientists hope we might detect signs that indicate the presence of life on those planets.

In 2020, scientists reported on the detection of phosphine (a possible biosignature) in the atmosphere of Venus. Did the Venutian clouds host life? Further measurements were unable to detect the gas, while another study suggested the initial detection may have mistaken phosphine for sulfur dioxide, a common gas that isn't a sign of life. A 2021 study highlighted the possibility that abiotic volcanic processes could explain the amounts of phosphine astronomers initially observed.

The uncertainty around the discovery of phosphine, and its possible abiotic sources on Venus, underscores some of the problems with the atmospheric biosignature method of life-detection. What's more, it leans on our understanding of Earth's biochemistry to form assumptions about how alien lifeforms may affect their home world. An interesting way of getting around this was presented in a 2022 paper by philosopher David Kinney and SETI principal investigator Chris Kempes. They suggest we should look at planets with the strangest atmospheres.

Kinney and Kempes think we should collect as much atmospheric data from as many exoplanets as possible to create a profile of the chemical composition of those planets. From there, our life detection efforts should be focused on worlds that are statistical outliers, or anomalous. Kinney and Kempes' approach isn't hung up on defining life in a particular way, but central to their argument are the core assumptions that living organisms affect the atmospheric chemistry of their planets, that life in the set of observable exoplanets is rare, and that there aren't common abiotic processes that mimic biological ones.

So far, of course, we don't have smoking-gun evidence of extraterrestrial life. But Sagan would be pleased that today's astrobiologists have expanded the perspectives on what life might be. Like the transition in our understanding of gravity from Newton to Einstein, a more powerful explanation of what life is as a system, and the conditions from which it could emerge, will better prepare us to answer the question, Are we alone in the universe?

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Why Reading Your Doctor's Notes Can Be Painful

A physician diagnoses the problem with medical notes—with a prescription for change

BY RAHUL PARIKH

I'M A PEDIATRICIAN and recently saw a patient whose parent very much wanted a certain test, even after I tried to explain why the test wasn't helpful or necessary. She wasn't persuaded, and rather than look obstinate or finicky, I ordered it.

In my summary notes from the visit, I wrote, "parent insists test be ordered." I paused and asked myself how the parent might feel if she read that, and whether it reflected her feeling at that moment. I rewrote it as "parent is very concerned about the diagnosis and therefore requests the test even after I informed her of its lack of benefit."

Ever since the 2021 institution of the 21st Century Cures Act, which contains a provision requiring patients to have ready access to doctors' notes, I've been thinking a lot about "open notes," as they're known. The rule in the Cures Act allows you to easily call up the notes on your phone or computer.

An advocacy group, Open Notes, instrumental in the passage of the act, concludes that patients who read the notes "feel more in control of their care, take better care of themselves," and have "stronger relationships with their doctors." When you read the notes after an appointment, however, I bet you've haven't always felt better.

Reading them is a fraught process. The notes might trigger uncertainty, even fear. I might write the cause of your child's headache is due to the flu, but other possible though less likely diagnoses include meningitis. Because you can't always get in touch with me right away for clarification, you are left alone with your anxiety. My notes can overwhelm you with jargon, causing you to go Googling for a clear translation. You might think I lack empathy with my dispassionate descriptions.

But before you write us off as insensitive or bad writers, let me tell you that open notes are challenging for doctors, too. Maybe explaining why will indeed improve your health, relationship with your doctor, and my profession.

First of all, we write a *lot*. Every patient we see in our exam room, every phone conversation we have with one from our desk, and every video visit from our webcam comes with our tradition and, now, obligation to write something in a patient's chart as a record of what transpired. We simply don't have the time to craft every sentence like Hemingway.

I know that good writing results from the writer having a clear picture of his reader. That image helps a writer have purpose and direction. A writer knows who he is talking to, what he wants to say, and how to say it. Doctors, though, have many audiences to satisfy, and so our notes, by trying to please everyone, can please no one.

Our first audience is other physicians. We write notes to remember what we heard and observed in our consultations with patients. It includes pieces like the concern that brought you in, what you told us about it, your vital signs, and what we found or did not find on your exam.

A good note makes our thinking clear as to the possible causes—what doctors call a differential diagnosis—of a patient's ailments; why we may exclude some diagnoses; what we are doing next—a test, a prescription, a referral to a specialist—that helps to better understand or address the problem. This piece, known as the "assessment and plan," also helps to keep communication flowing among different doctors who see a single patient over time.

But there are other audiences which muddle the clarity and conciseness of a clinical note.

First, there are the insurers, to whom we must justify our work to be paid. Doctors must play a game of including some very specific elements of documentation, so our services are clear. A common example includes a phrase that goes something like, "Spent 30 minutes with the patient discussing treatment, risks, benefits, and care options." If you see that, know it's jargon to provide your insurer with a sense of the complexity of our consultation. Regulators may also review notes, looking for specific content to demonstrate we are playing by the rules. The audience we dread the most, and are never out of our minds, are attorneys who may be hired if something bad happens to a patient we cared for. Because of this possibility, we often find ourselves adding many pieces of extraneous information as a preemptive legal defense.

All these masters lead to what is known as "note bloat." This phenomenon got even worse when we transitioned from paper notes to electronic ones. The various shortcuts and commands in electronic records makes it all too easy to buff up our notes. Last year, researchers looking at note bloat published a study in which they analyzed the length of 3 million clinical notes between 2009 and 2018. This was the period during which most doctors, hospitals, and health systems adopted electronic medical records. They found that median note length increased by 60 percent.

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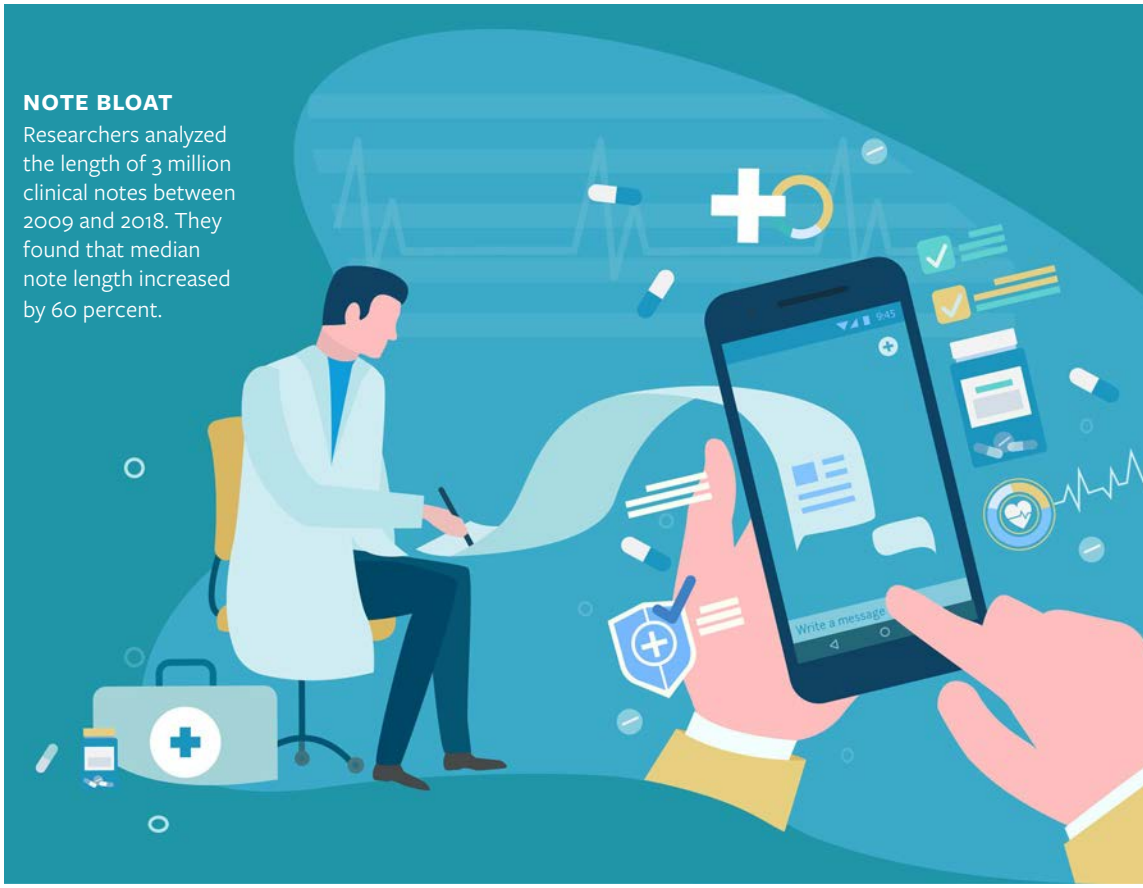

NOTE BLOAT
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In addition, the researchers looked at note redundancy, which they defined as one note containing the same, exact information about a patient as the note before it. Repetition is easy because of our ability to copy and paste, easily pull in past information from a patient's record, and use various kinds of templates in our notes that drag information from one note to the next. The study showed that median note redundancy increased 10.9 percentage points from 47.9 percent to 58.8 percent. Bloated notes have had the effect of "potentially limiting their use in patient care," concluded the authors.

When I read notes by my colleagues, trying to be thorough for all these audiences, I feel like I'm standing in the middle of a dense jungle with a dull machete, frustrated because it takes time and effort to cut through the bloat and redundancy for what I really need to know to do my part.

I can imagine how you feel, trying to separate the signal from the noise. In fact, following the passage of the 21st Century Cures Act, I'm literally prompted to imagine how you feel. Whenever I write a digital note, a little icon in my electronic medical records system pops up to remind me that what I write is visible to you. That cracks open what may be the most complex issue about open notes. Does serving these masters—colleagues, insurers, lawyers—affect what I write for you?

I can only speak for myself, no other doctors. But I admit that at least at this point, I'm not entirely focused on writing for you. Part of this is a habit, and part of it is my own view that my most important job is to communicate my thinking in a way that I and my colleagues

We have to embrace one crucial principle: Words matter.

can readily understand if, in the future, you land in their exam room. I prefer to be concise and, if necessary, direct the reader to other tabs in the electronic record for any supporting information that affected my clinical decision.

How our notes are affecting you is an active debate in the industry. Some scholars have argued they may do harm by creating a "nocebo effect." The nocebo effect is often described as the evil twin of the placebo effect—when what a physician says, writes, or does gives a patient the feeling of benefit, whether that benefit is proven or not. Nocebo, in contrast, is one in which something a physician does, says, or writes, creates and reinforces negative outcomes. Recent studies have quantified that up to two-thirds of side effects from the COVID-19 vaccines were attributable to what recipients were told about those effects before receiving it. Others have shown that men being treated for high blood pressure with medicines called beta-blockers were more likely to experience the side effect of erectile dysfunction if they were told about it compared to those who were not.

One scholar has identified another harmful impact of open notes: the use of language to describe patients that implies bias or negatively stigmatizes them. Examples of such language abound in our notes. Some are descriptors of our patients: "patient appears dishevelled." Others may describe how committed they seem to their plan of care: "patient is non-compliant or non-cooperative in taking her medications." Still others may describe the patient's answers to questions: "patient denies use of any alcohol, tobacco, or drug use." Studies have shown that doctors have used stigmatizing language to define patients who were diabetic, had substance-use issues, or suffered from chronic pain. Black patients are 2.5 times more likely than white patients to be described with negative, stigmatizing language.

Tossed-off, stigmatizing language has long been part of our shorthand, meant for an audience of us, doctors and other health professionals. When we face it toward you, it's easy to understand why you would take it personally, why our notes increase anxiety and erode your confidence and trust in us and in healthcare.

What's to be done to make the open notes more valuable for you and us? Doctors need to continue to adjust to the new reality. To do that as best we can, we are going to have to embrace one crucial principle: *Words matter*. We are going to have to come to terms with bloat, ruthlessly prioritizing what we write. Our notes will have to be plainer, with less shorthand. They are going to have to be more neutral, and respectful, even empathetic, toward our patients. Knowing patients are reading our notes can only help us reflect on and overcome our own implicit biases.

Some of us have started to change how we write our notes by not burying the lede. Traditionally, we put our crucial assessment and plan at the end of the note. More of us are putting it right at the top with supporting information (your history, vitals, exam, and test results) below it. If we as doctors can focus on making this portion of our note easy to find and understand, we can go a long way toward improving the notes for you.

You can help us out. Tell us what you do or don't like about the notes, how we might improve them. Like any piece of writing, our notes only get better if you read them and give us feedback. But I do humbly ask that you read the notes with the calmest version of yourself. Our words are not meant to worry, upset, or anger you. It's to make sure we use our words to give you the safest and best care we can.

RAHUL PARIKH is a physician and writer in the San Francisco Bay Area.


ASTRONOMY

The Remarkable Emptiness of Existence

Early scientists didn't know it, but we do now: The void in the universe is alive

BY PAUL M. SUTTER

IN 1654 A GERMAN SCIENTIST and politician named Otto von Guericke was supposed to be busy being the mayor of Magdeburg. But instead he was putting on a demonstration for lords of the Holy Roman Empire. With his newfangled invention, a vacuum pump, he sucked the air out of a copper sphere constructed of two hemispheres. He then had two teams of horses, 15 in each, attempt to pull the hemispheres apart. To the astonishment of the royal onlookers, the horses couldn't separate the hemispheres because of the overwhelming pressure of the atmosphere around them.

Von Guericke became obsessed by the idea of a vacuum after learning about the recent and radical idea of a heliocentric universe: a cosmos with the sun at the center and the planets whipping around it. But for this idea to work, the space between the planets had to be filled with nothing. Otherwise friction would slow the planets down.

Scientists, philosophers, and theologians across the globe had debated the existence of the vacuum for millennia, and here was von Guericke and a bunch of horses showing that it was real. But the idea of the vacuum remained uncomfortable, and only begrudgingly acknowledged. We might be able to artificially create a vacuum with enough cleverness here on Earth, but nature abhorred the idea. Scientists produced a compromise: The space of space was filled with a fifth element, an *aether*, a substance that did not have much in the way of manifest properties, but it most definitely wasn't nothing.

But as the quantum and cosmological revolutions of the 20th century arrived, scientists never found this aether and continued to turn up empty handed.

The more we looked, through increasingly powerful telescopes and microscopes, the more we discovered nothing. In the 1920s astronomer Edwin Hubble discovered that the Andromeda nebula was actually the Andromeda galaxy, an island home of billions of stars sitting a staggering 2.5 million light-years away. As far as we could tell, all those lonely light-years were filled with not much at all, just the occasional lost hydrogen

ANON MUENPROM / SHUTTERSTOCK

WILD HORSES COULDN'T DRAG THEM APART
Inventor Otto von Guericke's original vacuum pump and copper hemispheres are on display in the Deutsches Museum in Munich, Germany. When von Guericke sealed the hemispheres in a vacuum, they couldn't be separated by teams of horses.

The vacuum is singing to us, a harmony underlying reality itself.

atom or wandering photon. Compared to the relatively small size of galaxies themselves (our own Milky Way stretches across for a mere 100,000 light-years), the universe seemed dominated by absence.

At subatomic scales, scientists were also discovering atoms to be surprisingly empty places. If you were to rescale a hydrogen atom so that its nucleus was the size of a basketball, the nearest electron would sit around two miles away. With not so much as a lonely subatomic tumbleweed in between.

Nothing. Absolutely nothing. Continued experiments and observations only served to confirm that at scales both large and small, we appeared to live in an empty world.[1]

And then that nothingness cracked open. Within the emptiness that dominates the volume of an atom and the volume of the universe, physicists found something. Far from the sedate aether of yore, this something is strong enough to be tearing our universe apart. The void, it turns out, is alive.

In December 2022, an international team of astronomers released the results of their latest survey of galaxies, and their work has confirmed that the vacuum of spacetime is wreaking havoc across the cosmos.[2] They found that matter makes up only a minority contribution to the energy budget of the universe. Instead, most of the energy within the cosmos is contained in the vacuum, and that energy is dominating the future evolution of the universe.

Their work is the latest in a string of discoveries stretching back over two decades. In the late 1990s, two independent teams of astronomers discovered that the expansion of the universe is accelerating, meaning that our universe grows larger and larger, faster and faster every day. The exact present-day expansion rate is still a matter of some debate among cosmologists,[3] but the reality is clear: *Something* is making the universe blow up. It appears as a repulsive gravitational force, and we've named it dark energy.

The trick here is that the vacuum, first demonstrated by von Guericke all those centuries ago, is not as empty as it seems. If you were to take a box (or, following von Guericke's example, two hemispheres), and remove everything from it, including all the particles, all the light, all the everything, you would not be left with, strictly speaking, nothing. What you'd be left with is the vacuum of spacetime itself, which we've learned is an entity in its own right.

We live in a quantum universe; a universe where you can never be quite sure about anything. At the tiniest of scales, subatomic particles fizz and pop into existence, briefly experiencing the world of the living

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"Nothing contains all things. It is more precious than gold."

before returning back from where they came, disappearing from reality before they have a chance to meaningfully interact with anything else.

This phenomenon has various names: the quantum foam, the spacetime foam, vacuum fluctuations. This foam represents a fundamental energy to the vacuum of spacetime itself, a bare ground level on which all other physical interactions take place. In the language of quantum field theory, the offspring of the marriage of quantum mechanics and special relativity, quantum fields representing every kind of particle soak the vacuum of spacetime like crusty bread dipped in oil and vinegar. Those fields can't help but vibrate at a fundamental, quantum level. In this view, the vacuum is singing to us, a harmony underlying reality itself.

In our most advanced quantum theories, we can calculate the energy contained in the vacuum, and it's infinite.[4] As in, suffusing every cubic centimeter of space and time is an infinite amount of energy, the combined efforts of all those countless but effervescent particles. This isn't necessarily a problem for the physics that we're used to, because all the interactions of everyday experience sit "on top of" (for lack of a better term) that infinite tower of energy—it just makes the math a real pain to work with.

All this would be mathematically annoying but otherwise unremarkable except for the fact that in Einstein's general theory of relativity, vacuum energy has the curious ability to generate a repulsive gravitational force. We typically never notice such effects because the vacuum energy is swamped by all the normal mass within it (in von Guericke's case, the atmospheric pressure surrounding his hemispheres was the dominant force at play). But at the largest scales there's so much raw nothingness to the universe that these effects become manifest as an accelerated expansion. Recent research suggests that around 5 billion years ago, the matter in the universe diluted to the point that dark energy could come to the fore.[5] Today, it represents roughly 70 percent of the entire energy budget of the cosmos. Studies have shown that dark energy is presently in the act of ripping apart the large-scale structure of the universe, tearing apart superclusters of galaxies and disentangling the cosmic web before our eyes.[6]

And yet the acceleration isn't all that rapid. When we calculate how much vacuum energy is needed to create the *dark energy* effect, we only get a small number.

But our quantum understanding of vacuum energy says it should be infinite, or at least incredibly large. Definitely not small. This discrepancy between the theoretical energy of the vacuum and the observed value is one of the greatest mysteries in modern physics. And it leads to the question about what else might be lurking in the vast nothingness of our atoms and our universe. Perhaps von Guericke was right all along. "Nothing contains all things," he wrote. "It is more precious than gold, without beginning and end, more joyous than the perception of bountiful light, more noble than the blood of kings, comparable to the heavens, higher than the stars, more powerful than a stroke of lightening, perfect and blessed in every way."

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The Ecological Catastrophe You've Never Heard Of

In 12 minutes, a landslide, tsunami, and flood devastated a valley in Canada

BY MARA JOHNSON-GROH

ALONG CANADA'S RUGGED PACIFIC COASTLINE, late fall is a subdued season. A steady patter of rain falls on ferns as grizzly bears, bellies full of salmon, den down for winter. As the days grow short, the dense temperate rainforest sinks into a foggy winter torpor.

On a late November morning in 2020, the calm was fractured. It started with a roar, echoing from the mountains above a remote inlet, 130 miles northwest of Vancouver. Rocks destabilized by the retreat of a glacier plummeted down a mountain's steep slope. Part of a valley wall was collapsing.

RUNJA / SHUTTERSTOCK

In seconds, 50 million tons of rubble landed in the milky-turquoise waters of Elliot Lake at the glacier's foot. The landslide's impact shook the ground with rumbles so deep they were felt by seismometers around the world.

It didn't end there. The load of rocks that entered Elliot Lake forced up a tsunami over 300 feet tall—high as a skyscraper. The tsunami then blasted down the narrow lake at over 110 miles per hour. The water—enough to fill 5,400 Olympic-sized pools—burst out the far end, scouring a creek bed into a canyon as it descended the mountainside.

The water spared nothing. Giant Douglas fir and western hemlock trees were uprooted as if they were garden weeds. Fridge-sized boulders were tossed like Ping-Pong balls. Sections of the Elliot Creek river channel were dredged 150 feet deep in minutes.

The torrent reached the Southgate River Valley, some 6 miles from Elliot Lake, where it fanned out, bowling over trees and covering a square mile of crucial salmon-spawning habitat in silt and debris up to 16 feet deep. Some material was swept another 5 miles down the Southgate River into the ocean, spilling a plume of cold water and debris so large that it radically changed deep water temperature and chemistry.

Had anybody been in the path of destruction, says University of Northern British Columbia natural hazards specialist Marten Geertsema, "There's no way you could have escaped." By the time the bulk of the flood passed into the Southgate River, only about 12 minutes had elapsed. The damage, stretching from mountaintop to seafloor, was only beginning. Two years on, the full impact is still unfolding.

ERIK BLANEY, EMERGENCY PREPAREDNESS and Response Manager for First Nations Emergency Services Society of British Columbia first visited the area of the disaster in 2021. It was just up the coast from where he lives with his family. "It was mind-blowing," Blaney said. "It's something that your brain has a hard time comprehending how that even happened."

It happened because of a rare geological trifecta: landslide, tsunami, flood. Blaney and Geertsema, along with members of the Homalco First Nation, on whose land the event occurred, and a group of geologists, biologists, oceanographers, and researchers detailed the event in a 2022 report in *Geophysical Research Letters*.[1] They identified "rapid glacial retreat" for creating the conditions that allowed the cataclysm to happen.

Technically the event is classified as a glacial lake outburst flood. Occurring in the wake of retreating glaciers, these chain reactions are set up by thousands of years of geology, but strike in just minutes.

Millennia ago, glaciers around the world carved out deep valleys while pushing their bulk through mountain landscapes. Now, as temperatures rise, glaciers are melting and retreating. Glacial lakes can form when the melted water is dammed by leftover ice or material dropped as the glacier withdraws. These lakes are frequently flanked by steep slopes that, once propped up by glacial ice, are now freestanding and unstable. If a large landslide crashes into the lake, the water can rush out in a glacial lake outburst flood.

As our world warms, the conditions for glacial lake outburst floods are increasing. A 2020 *Nature Climate Change* paper found glacial lakes increased around 50 percent in number and volume from 1990 to 2018.[2] While not all glacial lakes are at high risk to cause catastrophic flooding, the disasters that do happen can claim dozens of lives and cost millions in damages.

A global tally of glacial lake outburst floods compiled in 2016 by Fiona Tweed at Staffordshire University and Jonathan Carrivick of the University of Leeds, found 1,384 events in the past thousand years. Over one-third affected communities, including more than 12,500 deaths. And that's just based on written records. These events "are going to be much more frequent in the future," Tweed says. "And that is partly because of climate change."

As our world warms, the conditions for glacial lake outburst floods are increasing.

The triggering events in some glacial lake outburst floods—landslides—are also thought to occur more often in a warming world with more frequent severe weather. A 2022 study of 3,000 landslides in the Austrian Alps published in *Communications Earth and Environment* found through modeling that 4 degrees Celsius of warming could lead to 45 percent more landslides in the region as heavier rainfall lubricates unstable slopes.[3] In mountainous areas, a warmer climate is also projected to reduce alpine permafrost, the long-frozen ground found in high mountain regions, which can further destabilize the ground.

Not all researchers agree there's been an uptick in glacial lake outburst floods yet, but most think that there will be. The current status quo in the frequency of events could be because we're in a waiting period, suggests Rupert Stuart-Smith, research associate in climate science and law at the Oxford Sustainable Law Programme. It takes time for a glacier to respond to a warming climate, more time for its meltwater to fill a lake, and yet more time before a slope in the right spot above the lake fails.

Lake Palcacocha, a glacial lake in the Peruvian Andes, is an infamous example of a disaster-in-waiting. In 1941, an outburst flood from the lake decimated the city of Huaraz, taking out a third of the town and killing at least 1,800 people. Today, human-induced climate change has increased the lake volume to 34 times its 1941 volume, and the town itself has grown from 11,000 to 120,000 people. Were a similar disaster to occur now, it could have a much larger impact.[4] Local officials are working to shore up the lake's banks and siphon off extra water, but the water levels—and flood risk—keep rising.

Landslides can do plenty of damage, even without glacial lakes. In 2021, a massive rock and glacial ice avalanche 50 percent larger in volume than the Elliot Creek landslide crashed through the Chamoli district of the Indian Himalayas. The debris rushed through a set of valleys, tossing huge boulders, tearing down roads, destroying two hydropower projects, and claiming 200 lives along the way. Later, satellite images showed sediment from the event 560 miles downstream in the Ganges River. It may have gone farther, but that's as far as scientists could track.

WHILE THE FLOODWATERS from the Elliot Creek disaster have receded, the damage is long lasting. Before the flood, the area provided fertile spawning grounds for chum, pink, and coho salmon and cutthroat trout. Now, impacted sections are a barren moonscape of rocks and debris.

Today, the Elliot Creek bed is still highly unstable and leeching sediment downstream, where it continues to clog the Southgate River and the gills of fish trying to swim there. Even once the debris and turbidity levels settle, the silty riverbed will no longer be suitable spawning grounds for some species, like chum salmon, who prefer pebbly-bottomed waters. Additionally, the shady canopies that once cooled the riverbanks to fish nursery-friendly temperatures have been washed away.

THE AFTERMATH Researchers take water samples from the river on a post-disaster visit to the Southgate River.

ERIK BLANEY

The Homalco Nation is considering efforts to help redirect the river through the remaining tree stands, but the creek is still too unstable. During an unprecedented heatwave in June 2021, melted snowpack from the surrounding mountains caused the river to dramatically change course at least five times in just three days. While the creek is still settling on its new direction—something that could take years—any efforts to choose a path for the creek could be undone by an extreme rainstorm or heatwave.

Cost is also an issue. "When you start looking at the impacts of this [event], you know, we're looking in the billions probably [for] restoration," Blaney says.

Blaney and other researchers from the Homalco Nation, British Columbian government, and the Hakai Institute, a scientific research center based in the area, are monitoring the ongoing changes in the region with temperature, oxygen, and turbidity sensors, and cameras. That information will guide the Homalco Nation in making fish harvest quotas and land use decisions, including logging and mining, Blaney says.

The full impact of the disaster will likely be spread over years as salmon populations—already at historic lows due to overfishing, spawning habitat loss, and climate change—are affected. This will create its own cascade of ecological and economic effects as the decrease in salmon hits local harvesters, including community members, grizzly bears, and tourism operators.

"It's such a massive event that it's really hard to count the losses, I guess because they're not instantly realized," Blaney says. "I think over the next four or five years when there's 80 to 90 percent less salmon hitting

PATH OF DESTRUCTION

The landslide debris spread out from Elliot Creek into the Southgate River, taking out trees and degrading salmon habitat.

MARTEN GEERTSEMA

the plates in the [Homalco] community, that's when people are going to really realize, 'holy cow, this event had a massive impact on our seafood protein intake.' "

GEERTSEMA, BLANEY, AND OTHERS in the Homalco Nation worry this event is the first of many. Across British Columbia, glacial lakes have nearly doubled in volume in the past 30 years. An assessment of glacial lakes in Homalco lands revealed at least four other areas of concern. Researchers have identified 178 Southgate River-like watersheds that could experience similar outburst flood disasters along the British Columbian-Alaskan coast.

If more floods are expected, the question becomes when. In recent years, improved seismometer sensitivity, lidar, and satellite imaging are providing scientists a boost in understanding these events, but predicting a landslide is nearly impossible.

"Predicting where something might happen is the easiest [part]," Geertsema says. "Predicting when it will happen is more difficult."

Some slides—Elliot Creek and Chamoli included—show a slow creep in the months or years leading up to an event. Others give way without warning, making it hard to provide notice to anyone who might be in harm's way.

Most of the time, researchers must sift through the debris after the fact like detectives to figure out what happened. But the Elliot Creek disaster occurred in a richly studied area—providing researchers the equivalent of video surveillance of a crime scene.

In recent years, lidar data—a remote sensing technique using lasers that can provide precise 3-D surface mapping—of the Elliot Creek watershed and water samples from Bute Inlet have been collected by a forestry company and the Hakai Institute. Comparing this with similar data collected after the slide, Geertsema and his colleagues had a wealth of information to plug into computer models to map the event's destructive path from sky to sea.

The researchers' results show how the landscape changed in incredible detail. In its rush downhill, the flood eroded tens of feet of sediment in some areas and deposited enough to bury a truck in others. Analysis of the water samples showed that upon entering the ocean, the water cooled the inlet depths half a degree Celsius—instantaneously bucking a 70-year trend that has seen 1.3 degrees Celsius

These chain reactions are set up by thousands of years of geology, but strike in just minutes.

warming—and dramatically increased oxygen levels. Even seven weeks after the flood, turbidity levels—which measure how much sediment clouds the water—in the Southgate River were up to 32 times higher at the affected area than they were farther upstream, where the flood didn't reach.

While the researchers have pieced together the minutiae of what happened, they still don't know exactly what triggered the initial landslide. The precise cause will likely never be pinpointed, but it's clear to the researchers that the recent accelerated retreat of the glacier, which had shrunk by some 1.5 miles in the past 50 years, played a crucial role.

With rising global temperatures, those living in the shadows of glaciers will likely see more catastrophes in coming years. But with ongoing monitoring and an increased understanding of glacial lake outburst floods through studies like the one at Elliot Creek, there's hope future events can be mitigated by improving risk assessments and planning future developments and population centers more mindfully.

"We are in crisis mode," Blaney says. "We really need to come together to figure this out."

MARA JOHNSON-GROH is a freelance science writer and photographer who writes about everything under the sun, and even things beyond it. Her work has been featured in publications such as *Science News*, *Scientific American*, NASA, *Discover*, and more.

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The Ghostwriter

In a work of fiction, holograms and memory collide

BY THAÏS MILLER

MY FIRST INSTINCT, to be honest, is always to break them. When Evan Chen and his latest holographic man appear near the entrance of the fruit aisle of Vegetale Market, my hand twitches on my tablet, my desire itching to the surface. I repress the sensation, always keeping my composure. Evan waves at me, twenty feet away. The grocery store is unusually packed for a Saturday night in Pacific Heights. Costumed children run in front of their parents, who are carrying green baskets full of last-minute organic Halloween candy. With each step, Evan's petite frame keeps getting pushed back as though he is swimming against a current of zombies, clowns, presidents, and aliens. Finally, he gets close enough to me that I can observe his holographic man clearly, uninterrupted. In leather boots caked with mud, the holographic man clomps toward me and the banana rack. He releases patches of fake, glowing, translucent dirt with each step as though he has just emerged out of a grave, or rather, dug himself out of one. He reminds me of a skeleton. I can see his collarbones and ribs protruding from under his nearly-translucent skin, exposed by a loose collared shirt missing several buttons. He has a long, thin beard. He can't be older than twenty-five, at least fifteen years younger than Evan and I.

"Good casting, great wardrobe," I tell Evan.

Evan stands a good ten feet back, projecting the hologram from his belt buckle. With his hands resting on his hips and his elbows back behind him, he juts his crotch out toward me as though trying to say, check out my big dick energy. He hasn't changed since we met at USC almost twenty years ago. Sometimes I think he followed me to the Bay when I first moved here after college. He stands shorter than the hologram by about a foot. His greasy salt and pepper hair sticks to his forehead.

To get a better look and get the hair out of my eyes, I put my long dark hair into a low ponytail. I inspect the hologram more closely. His thumbs remain hooked around the straps of a bag, which looks more like a large potato sack with straps than a backpack. The large metallic pans tied to his sack clang as he finally drops the bag at my feet.

"Wow," I say. "Nice sound engineering."

"Do you want to hear it again?" Evan asks and, before I can answer, he presses a button on his watch so that the hologram picks up the sack again and drops it down.

Logically, I know that Evan is likely transmitting the sound from a device he's wearing, his belt or watch, but the way the sound hits my ear enables my mind to play a trick on me and make my body believe that the sound is coming directly from the image right in front of me. I reach down to touch the sack, and my hand goes straight through it.

Sweat stains rim the shoulders of the hologram's collarless, long-sleeved shirt, which remind me of long underwear. The man's shirt is so abused it is difficult to tell what the original color had been. He wipes his face with a kerchief from his jeans pocket, the legacy brand Cohn's broadly displayed.

A few customers pause to watch, and Evan smiles from ear to ear. An elderly customer tries to walk in front of him to grab some local grapes, and Evan blocks him, grabbing a bunch for him so that the projection of the hologram isn't disrupted. In doing so, Evan sets off one of my sensors, and my holographic actor impersonating Cesar Chavez appears, flickering, projected from lights running along the ceiling of the grocery store. He was one of my first and few designs to go state-wide; I still remember filming that actor. My hologram clears his throat, "In 1965, eight hundred Filipino-American farm workers demanded a raise in hourly wages." The actor's voice, which emanates from speakers embedded in the fruit stand, sounds metallic and distant compared to Evan's hologram. My digital recording already looks hazy and out-of-focus in comparison to Evan's crisp design. It's amazing how quickly the quality of recording technology improves, how fast former creations fall behind. I make a note on my tablet to look into it. I wave Evan to stand closer to me and Chavez suddenly disappears. For a split second after his departure, my signature watermark hangs in the air like smoke: DESIGNED EXCLUSIVELY FOR VEGETALE MARKET BY MIA DEZHNYOV.

"Check this out." Evan hits a button on his wristwatch and the hologram opens his mouth, leaning his face upward. I have to get on my tippy-toes in order to inspect him as a dentist might. I am shorter than "the average person" Evan designed for; in other words, I am not one of Cohn's male customers that he planned for. Given his own height, he should know better.

"Oh, oops." Evan plays around with his watch until his hologram gazes down at me.

The hologram's open mouth exposes a few missing teeth and one gold tooth. His face is dirt-lined, wrinkled, and sunburnt.

"Good makeup."

"Well, here's the thing." Evan lowers his deep, bass voice. "It's not makeup."

"Huh?"

Evan whispers, "He's unhoused. It's part of the client's social corporate responsibility campaign. All the actors were picked up off the street."

PAGES 60-61: TASNUVA ELAHI, WITH IMAGES FROM DVO, CHANNARONG PHERNGJANDA, AND SENSVECTOR / SHUTTERSTOCK

My instinct is always, how can I fool this machine?

"What?!" My jaw drops. My tablet slips out of my hands, falling onto the floor. My head is spinning. And I just examined him, inspecting his teeth the way a slave owner might have. I pick up my tablet. Before I can process the ethical implications of all this, Evan hits a button on his watch, and his hologram moves closer to me.

"Would you like to ask me some questions about my experiences as a miner during the Gold Rush?" His smoker's voice is clear, a fresh recording, much higher quality than my holographic Chavez. He pauses, smiling, blinking unnaturally.

My desire to break him, to break both Evan's latest prototype and Evan's ego, increases. I answer the hologram, "Sure."

But the hologram doesn't hear me.

"Sure," I say again, a little louder.

Evan furrows his eyebrows and glares down at his watch. "Wait, I'm not sure why—"

This happens all the time, especially with male engineers. It's the kind of mistake that appeared in my grandfather's prototypes. I roll my eyes. Lowering my voice register from soprano to baritone, I say again, "*Sure.*"

"Great." The hologram suddenly looks in my direction, staring at my forehead, and begins moving more naturally again.

I look at Evan. "Speech Recognition Software 101: design for all voice registers, not just your own."

Evan gazes down at his watch, tapping it as though taking notes. He shakes his head and mutters, "I knew you'd be the perfect person to test him on. You always did better in those classes than me."

"What are your questions?" the hologram asks me.

The truth is, yes, I have genuine questions for a gold miner, which Evan has probably already intuited. What inspired me to work as a holographic programmer in the first place was an intense curiosity, a desire to communicate with the ghosts of the past. But this isn't a ghost; this is a machine with the face of an actor—an unhoused actor—re-enacting the past. His script might have as much historical insight as a Gold Rush expert, or even a re-enactor, but he won't know what it felt like to be there. My instinct is always, how can I fool this machine? What can I ask about that it won't have an answer for? When a possibility comes to mind, I grin. Let the fun begin.

"*What do you smell like?*" I ask the holographic man in a lower register so he'll understand me.

The hologram pauses, taking in my question, struggling to load, to find an answer. Engineers such as Evan train these holograms to recognize certain keywords and synthesize them with the client's pre-authorized brand bible. But sometimes customers ask questions that don't quite align with the messaging the clients want to give them. Just when I think I've stumped him, the hologram answers, "Wet soil, urine, tobacco, buckwheat, and B.O."

"Wow," I say to Evan, "you did your research when designing this one."

He blushes. "Thanks, Mia." He clicks a button on his watch and the hologram takes a little bow toward me. As he struggles to get the hologram to stand upright again, he says, "Remember in college how everyone was always modeling their senior projects after those lame concerts? Tupac at Coachella.

EX_ARTIST/ SHUTTERSTOCK

Elvis Presley singing with Céline Dion. While you ... you were spending every day at the Shoah Foundation studying Spielberg's thirty-five-year-old recordings of Holocaust survivors. You took the work seriously from the start." The hologram finally stands up straight again. "I'd love to share the roll-out plan with you over dinner—"

"But no one would ever really say that in a conversation, would they?" I interrupt him. "Imagine just coming out and saying to someone that you stink. And surely, the client doesn't want anyone to think their jeans might stink either. If I had written it, I would have said, 'None of your damn business.' But then again, I'm sure that's not in their brand bible and I'm not writing for this client."

When I take too long in asking another question, the hologram dives into monologue. "I'm just another argonaut in search of El Dorado . . ." As the hologram talks, he takes out a small leather envelope from his pants pocket. He extracts a wrinkled, dirty piece of holographic paper and places it on his open-faced palm. Then he pinches out pieces of tobacco onto the paper. He starts rolling a cigarette, licking the seams shut. Then he takes out a cast iron box of matches with old, saloon style typeface that says, "SELF-CLOSING."

My breath stops. I recognize that oddly specific prop. My grandfather bought it at an antique sale for me when I was in college, two decades ago. The store owner told us that they were used during the Civil War. The timing was perfect. My grandfather said that we could use it for my first hologram. I interrupt the hologram's monologue. I say in my deep voice, "*Who gave you those matches?*"

The hologram pauses almost as though reloading. "Well, these here matches I bought from a peddler in Chinatown—"

"Evan," I say in my normal voice, "Where did you see those matches?"

He looks away from me, down at his watch. "I-I must've just Googled them."

I walk toward him until I've stepped through the talking hologram, and I am standing just a foot away from Evan. He backs away from me, step by step. When he gets too close to the ears of corn, a holographic Ohlone family appears pointing accusingly at a pale holographic Spanish missionary who kidnapped the holographic Indigenous child trembling beside him. We continue this odd tango, me forward, Evan and his hologram backward, until we have passed the corn and my display holograms disappear and my watermark appears in a puff of fake smoke. I stare at him until he meets my eyes.

"Okay, okay," he says. "You know, your work influences me. It's not 'plagiarism' "—he uses air quotes—"or anything like that. I just saw it on one of your old holograms in North Beach recently."

"One of mine?"

"It must've been yours. It had the watermark to prove it."

"No, that's impossible." Once I signed my contract with Vegetale Market five years ago, all of my older designs were put out of commission, that was one of their stipulations: exclusivity.

"Look, I'm sorry, I didn't mean to steal your idea. I-I was just using him as inspiration."

"Him?"

"The doctor."

My first hologram, my senior thesis in college. I didn't know any professional actors then, so I got my grandfather to act in the role assigned to me by my professor at random: an elderly nineteenth-century doctor. I knew my grandfather's health was fading, and I wanted to create a hologram so that I could remember him forever, preserve his image before the end of his life. I recorded him just a year before his death. Either someone is operating the hologram illegally or he's gone rogue. The former is sleezy but probable, the latter is highly unlikely but enough to pique my interest. The whole situation is copyright

violation at worst, actual artificial intelligence at best. "Show me," I tell Evan.

He switches off his holographic goldminer. His watermark—his name dancing from side to side—dangles in the air for a moment before disappearing. He smiles. "Sure. My car's downstairs."

I take off my apron, and we hustle down the stairs into the Vegetale Market garage. Evan hits a button on his phone and a self-driving gray Electride approaches us, lights on. Touching his watch, he unlocks and opens the front driver's side door and the front passenger's side door, which flap upward as wing doors. We quickly get inside. I move an empty bottle of kombucha off my seat and sit down, the doors closing automatically behind us. The car smells like green onions. He plugs the destination into the car's navigation system and we are off, a fifteen-minute drive to North Beach. As I neatly fold my apron and place it in my back pocket, he turns on a "Dope Beats" playlist and the car rattles and shakes with each bass note. For a moment, I wonder if he has been lying to me and this was just some excuse to get me in his car with him. Around us are half-empty self-driving electric vehicles with drivers watching music videos and movies on the screens in front of them. Ash the size of snowflakes from a nearby fire slowly rains down onto the car. I watch the families in Halloween costumes walking on the sidewalk, wearing gas masks and respirators.

"I have a spare mask in the glove compartment." He opens the compartment in front of me.

"Thanks." I take out the translucent respirator with clear safety goggles attached.

The car drives to Stockton Street, getting caught in traffic in front of the subway station. Near the entrance, an entire holographic theater is on display. Holographic actors dressed as Jack London and Mark Twain talk to a family wearing respirators and I ♥SF sweatshirts. The holograms look totally unaffected by the soot surrounding them. Twain's white hair, white mustache, and white three-piece suit are so clean and bright that they are nearly blinding. I bet that keeps the neighbors up at night. This subway station has become an amusement park ride. I shift in my seat, uncomfortable. Every time I see them, I think: We are in Chinatown, in the Rose Pak Station. The new Bay Transit Authority couldn't find a single Asian-American historical figure to feature here? Why does every station have the same holograms? These were the victors of history, the ones we already remember. When the family walks inside the station, the holograms disappear, replaced by the watermark DESIGNED EXCLUSIVELY FOR BTA BY WHITE & BUCHANAN, LLC. Unlike my watermark, the name doesn't disappear in a puff of smoke. Instead, the name glows hotter and then dulls to a branding or burn mark before disappearing.

The whole situation is copyright violation at worst, actual artificial intelligence at best.

"I'm sorry you didn't get the BTA deal. You deserved it. And hey, you were a finalist, right?" Evan asks me.

I nod. I had proposed that we interview elderly, living legends, before their deaths. We could feature a different figure at each station, who held historical significance for that neighborhood, to preserve their legacies. "Did you bid on it?" I ask him.

He chuckles. "Yeah, I'm pretty sure everyone we went to school with did."

"What was your concept?" I ask him.

"Hippies."

"Hippies?"

"Hippies"—he spreads his hands out like fans in front of him—"everywhere." He rests his hands in his lap. "My great-grandparents were Deadheads. I wanted to dress up a bunch of actors in their old tie-dye. I didn't make it to the second round. BTA said they wanted a cleaner image. They also said it was too broad; it wasn't character-driven enough." He pauses. "You know," his tone changes to one of anger, resentment, "the greatest thing that differentiates holographic theater from real life is the belief that characters can actually drive their own stories, that they have some control."

He has a point. Most of the time, we are mere observers, passive participants, figments of our circumstances and environment, pushed around by the waves of social context and history and the whims of powerful systems, not even individuals. We're getting shuttled around in this Electride right now. That's why when we tell stories, we capture moments where people acted of their own accord. In real life, Evan and I get rejected from one opportunity to the next, only to be accepted by one random client and that changes the course of our lives. Events happen to us beyond our control all the time in reality. I may not have even started creating holograms had it not been my grandfather's job. He'd been a famous holographic designer. Had I not been exposed to equipment at an early age and received my family's constant encouragement and extracurricular training, how would I have ever broken into this field? I always felt a responsibility to live up to my grandfather's desire that I create a strong family legacy in this industry. Despite a tough exterior, I'm not a brave person. I'm an opinionated perfectionist, but I never set out on my own path, separate from my family. I like making clients happy. Being in control, making a decision is so rare. For any of us. Evan isn't even driving his own car.

The traffic starts to dissipate, and the car turns right and then left. When the car finally slows at Broadway and Grant, we put on our masks and get out. The car will continue to circle the block until it finds parking or until we leave, whichever comes first. This afternoon, I hear at least ten different muffled languages on the street. Before the placement of holograms around the city, I was used to seeing a mixture of suits and slobs, techies and unhoused people, but this is different. Rounding the corner onto Columbus Ave., four holographic men in old Air Force uniforms talk to a holographic racehorse jockey in uniform carrying a whip. Ashes float through them. Their fresh and immaculate costumes remain unblemished. Outside City Lights, a holographic Lawrence Ferlinghetti is reading his poetry aloud. I had envisioned poetry readings by Tongo Eisen-Martin, Liala Zaray, and Thea Matthews for the BTA. Most had already died since the original pitch, so in a sense, I had lost on two fronts. I had lost to time, and BTA told me it was too expensive. The director wanted one mass, homogenous, clean distribution plan; one blazing-white portrait of the city; a San Francisco Disneyland. None of it made any sense, especially not for this city.

Ash the size of snowflakes from a nearby fire slowly rains down onto the car.

Evan points to me that we have to cross the street. "I saw him over there." His voice sounds a little faint with his respirator on. We walk toward the Condor Club and Big Al's. I watch Evan's self-driving Electride continue to drive itself around the block in search of parking. For a moment, I wonder if my old holographic doctor is inside the strip club.

I feel a sudden jolt of hope that perhaps my first hologram has become cognizant, and he's just out having a good time. Once we arrive in front of the club, a swarm of holographic women in flapper dresses spill out of the taqueria next to the strip club. A man in green fatigues, who isn't wearing a gas mask, walks behind them. His hair is greased back, and a cigarette balances behind his ear. The women adjust their movements so that he can get past, which makes me think that he is also a hologram until he bumps into me, and I realize that he is real. He resembles someone straight out of the fifties. It's just a good Halloween costume, a strong performance of the past. He mutters, "*¡Perdone!*" and continues shuffling through the crowd of holograms and tourists ahead of me. I realize that the flappers reacted to his presence, they readjusted their movement so that he wouldn't walk right through them. I've never seen holograms with such accurate spatial awareness before. The machines are always a little off. The flappers walk up the hill on Grant Ave. toward Caffe Trieste. I've heard of new technology that allows some holograms to have real-time reactions to the scenes around them, holograms triggered by real people and holograms that can trigger the actions of other holograms, but I haven't observed them in person. North Beach seems to have become the new testing ground for these prototypes.

A holographic woman suddenly faints on the sidewalk in front of us, in front of the windows of the Condor Club. The woman's hoop skirt reaches toward the sky, exposing white bloomers to everyone who passes. She appears trapped in her caged crinoline. Who would program her to act this way? I'm so sick of male engineers programming another damsel in distress. Or is she just acting, staying in character, genuinely reacting, as a woman from the late nineteenth century might, to a late twenty-first-century strip club? Several real topless tattooed dancers inside come out to catch what's going on with the latest holographic installation. One of them hastily puts on a mask, but most of them don't.

Perhaps triggered by the scream, a holographic horse-drawn ambulance cart drives by, and Evan's real self-driving car, unsure if the cart is real or projected, swerves past it to avoid crashing into it. A holographic man—my grandfather—wearing a bowler hat and a long white coat gets out of the cart. It's strange to discover him moving around in character after all of these years. For some reason at the sight of him, I have a sudden memory of his smell: Marlboro cigarettes and oranges. He loved both. My mind is playing with me. I pinch myself. Focus. A small leather case in hand, he runs over to the woman.

"Doctor!" I call out to him, waving my arms in front of his face, testing to find out how responsive the hologram will be, how accurate his facial recognition and spatial awareness will be. Has his code been altered by someone else? Is it true? Has he started running on his own, without human intervention? Am I looking at the first sentient hologram? Is he aware of who he is? My grandfather made millions creating the most realistic, cutting-edge holograms; he was an expert who trained other experts, and me. His legacy became my inheritance. I've always felt a duty to preserve the past and present for the future. In a moment of pure desperation, a desire deep inside of me erupts, and I shout, "Grandpa!"

He completely ignores me, tending to the patient in front of him. I feel immobilized. All I can do is watch. On the sidewalk in front of the Condor Club, the holographic doctor takes out a small glass bottle with a corkscrew and a large injection needle from his leather bag. His image is hazy and slightly blurred compared to other holograms today, because of the old technology I'd originally used to record him, but he's still there. I'm not the only one who is beginning to confuse the imagined past

with present reality. His reaction and treatment seem drastic, unnecessary, and cruel given that the holographic woman merely fainted. But the scene also feels uncomfortably real. In college, I'd researched his character meticulously, and he hasn't failed me in his veracity. Yes, yes, this is what a doctor would have done to a woman back then. One patient testimony I read had compared them to butchers treating patients as pieces of meat. I had wanted to show the truth. Perhaps that's why at the time he had been so unpopular, and why, ultimately, I didn't get the BTA deal. Yeah, Evan is right: All of my classmates at USC designed their work to reproduce dead celebrities. I'm tired of holographic designers excusing their work as nostalgia so they can lie about history. At least Spielberg's holographic theater hadn't been for the famous; it was for the victims of genocide, so we wouldn't forget their stories. Long after his death, his work convinced me at an early age that we should be exposing people to what the past was really like, to remind people today that we should behave differently. The holographic doctor aims the needle toward the woman in the hoop skirt.

"Stop! Stop!" one of the maskless exotic dancers attempts to pull back his shoulder, intervene, stop him from touching the woman in the hoop skirt who has fainted, forgetting for a moment that none of this is real. The real woman's hand just slips through the hologram's body.

The holographic doctor in the bowler hat throws his hands up in the air. "Well, it's either this or we try laudanum!" My grandfather's voice sounds tinny, far away. I can hear traces of his Russian accent, his souvenir from fleeing the Soviet Union with his parents as a teenager in the late nineteen eighties, over eighty years ago. I remember filming him. It feels simultaneously far and close, stale and fresh. I recorded him twenty years ago, but it also feels as though it happened a day ago. I look around trying to locate the source of the light, trying to identify from where he and the cart are being projected.

Then the dancer yells at him, "Don't move her! Don't touch her! Leave her alone!" Tears stream from her eyes, and I can't tell if it's from the smoke.

The other dancers attempt to shoo the holographic doctor away from the unconscious holographic woman. The doctor finally gives up, snapping his leather bag shut. He stands up and lights a cigarette, using a match from the self-closing box. Evan points at it. Then he gets back into the horse-drawn cart, which, although not made of any real materials, remains stuck in the traffic jam that is now taking over the entirety of Columbus Ave. For a second, I wonder if he'll go to the hospital to share his knowledge of archaic treatments with patients in the waiting room, but then I identify the stream of light coming from an open window in the building across the street. I realize that he's not going anywhere. I point up to the top floor of the apartment building across the street, and Evan gawks at the building. The window is three stories above the New Sun Hong Kong Restaurant. Suddenly, the projection of the doctor and the horse-drawn ambulance cart switch off and they disappear, my watermark appearing. The window slams shut. Someone is inside, manually projecting my old design without my permission.

I run across the street toward the restaurant. I hear Evan's footsteps running after me. On the right-hand side of the building, there is a small doorway with a pale blue and white neon sign overhead that says HOTEL. I open the door and see an old woman without a mask standing behind the counter.

She looks up. "Can I help you?" The woman flickers, and I realize that she is a hologram as well, working as the front desk attendant of this hotel. I run up the stairs. "Hey, wait! Stop!" she yells after me, but there is nothing she can do.

Most of the time, we are mere observers, passive participants, figments of our circumstances and environment.

I run up the first flight of stairs, then the next, then the last. Out of breath, I stupidly take off my gas mask only to find it even more difficult to breathe, dust particles scattered around me. The smell of crab wafts into the hallway from the restaurant downstairs. I hear Evan below, trying to reassure the hologram at the front desk and then making his way more slowly up each creaking step. Gasping, my lungs filled with dust and ash particles leaking through the old windowsills, I stare at the hallway ahead. I feel dizzy, disoriented. I try to gauge my direction. Which of these rooms would have a window facing the street? The rooms to my left. I start with the first door. I try turning the handle, which is locked, of course, and then knocking loudly. "Hello? Is anyone there?"

When no one answers, I go to the next room, knocking loudly on the door. I've tried every door in the hall by the time that Evan has reached the top of the stairs. He takes off his mask, and I hear him panting as well. He bends over, placing his hands on his knees. An old man and a woman across the hall open their doors, peaking their heads into the hallway.

"Hologram?" I ask them. "Are you running a hologram? Do you know anyone running a hologram on this floor? Is there any other way to get out of the building from here?" I wonder if the projectionist has already snuck out on a fire escape without me knowing.

The guests look at me confused, and I try to look past the old man into his room, to see if I can spot any projection machines. I realize that this SRO hotel is his home. Evan begins to apologize to the two people in the hall in Mandarin. I spot a door at the end of the hall suddenly open, but no one comes out. The door just opens a crack and stays there as though someone has opened it for me to come inside, to follow them.

"Mia!" Evan calls after me. "Hold on!"

I push the door further open and walk over the threshold. I discover an old Yamaha digital desk in one corner of the small studio. An LED projector and a Cisco Telepresence speaker system stand next to one of the closed windows. I hear the door shut behind me, and I quickly turn around. Evan stands in front of the door, smiling. A lamp suddenly turns on, revealing an older man in a hoodie sitting in an armchair. "Thanks for your help, Evan. Welcome, Mia. Why don't you take a seat?"

I don't move. "What's going on, Evan?"

"All I want is a conversation," the man in the chair says.

For a moment, I wonder if I'm speaking to the CEO of Cohn's, but I don't recognize him. He seems older, with wrinkled hands. He holds his hands together and tents his fingers, touching them to his lips, waiting.

"Sorry for the smoke and mirrors. Just hear him out," Evan says behind me. "This is a great opportunity."

The man in the chair motions for me to sit on the edge of the bed near him. I don't move.

The man clears his throat. "I apologize that I had to lure you out here with one of your old designs, but we needed to get your attention, quickly, and we wanted to

"Isn't that what drew you here? To see your grandfather? To interact with him one last time?"

meet in private, on neutral ground. This is strictly confidential, and I know that your current employer wouldn't be thrilled with our meeting."

"Who are you?"

"Phil Elystan. I'm the Chief Innovation Officer for Envirtual."

Folding my arms across my chest, I lean against the wall, finally catching my breath. So he works for the largest virtual and augmented reality company in the U.S. With every passing second, I feel more disappointed. "What do you want, Phil?"

"We want you to come work for us."

"That's impossible, I'm under—"

"On the down low, of course. Not 'officially,' just in spirit. A ghostwriter of sorts. We know you're under contract. Think of the role as a kind of anonymous advisor. Evan would be more than happy to serve as the front man. Isn't that right, Evan?"

I quickly turn to look at Evan. When our eyes meet, he wipes the grin off his face.

"We want to build a virtual theme park," Phil continues, "and we want you to design it."

"A theme park?"

He looks out the window for a moment. "Not so different from what you saw today in the street."

"I'm not interested in building a San Francisco Disneyland."

"No." Phil shakes his head. "This is a VR space that anyone can access from anywhere, where the past comes alive, but specifically, where you can visit the people that you love who have passed on."

"Sounds like a cemetery."

Evan chuckles. "What did I tell you?" he says to the man in the chair. "She's the best."

"It's a VR cemetery?" I ask.

"It's a full-service memory database," Phil clarifies. "We complete digital scans and interviews while people are alive and then we store them along with all of their social media content, for a small price compared to their value, so that their relatives can come visit them anytime they like using our headsets. We create an AI chatbot that imitates the voice of each subject so that visitors can enjoy brief conversations. Isn't that what drew you here? To see your grandfather? To interact with him one last time?"

"How did you—?"

"USC's library archives keeps all of their students' theses on file, and our facial recognition software spotted him right away. We have access to all of your old designs in fact. Evan here is a bit smarter than he looks and a decent systems hacker. Think about what it meant to you to see him again, to imagine interacting with him again. Wasn't it powerful? Now monetize that sensation."

What a manipulative leech. I turn away from him and begin walking toward the door.

I hear Phil tapping the Yamaha digital desk. My grandfather's voice resonates in the speakers. "Mia," he says.

I realize that Phil is plugging in a new script, modifying my old design.

"We're all haunted by the past," my grandfather's voice says.

Phil pauses and watches me. "Think about the implications. This technology could be used in therapy, recovery. It could heal so many people tormented by time."

It sounds more like he wants to torment people for his own benefit rather than heal them. I ignore him. "Thanks for the

introduction, Evan." Now that I know who he's really been working for, it doesn't surprise me at all that he'd take advantage of an unhoused person, manipulating him for his own gain.

Evan blocks my path, leaning his body against the door behind him.

Phil adds, "You'll do what we ask or we'll delete the original."

I spin around and look at Phil. "You'll what?"

"We'll delete the original recording, erase him from the digital present. One less memory of your grandfather preserved. Gone. And then we'll delete the others, your originals, your legacy. Everything you've ever worked toward, we'll destroy it. With your body of work, you were probably hoping to donate it to a library one day. Well, we won't stop coming after you until you do as you're told."

Evan puts his sweaty hand on my arm. "Mia, he's serious." He lowers his voice, "Look, I'm sorry, but don't mess around with these guys." I notice the hair on Evan's arm is standing up, covered in dust. I wonder for a moment if they've threatened him as well to get to me. I get the sense they didn't give him any choice.

I turn around and walk toward the table, listening to my grandfather's voice as he recites his lines, the ones that I wrote for him. His performance was our sole collaboration. I gaze at a miniature model of his projection on the table in front of me. There was a version of me in the past, perhaps at the time when I filmed my grandfather, who would have listened to Phil's offer and even accepted it, a version that was trained to be good and follow instructions and just took for granted that powerful men ran everything, and I would always be a pawn in their schemes. The lone woman breaking the curve on tests. The lone woman in pitch meetings. Now the lone woman designing an entire VR theme park. Isn't that a type of victory? It's being rewarded for going with the flow, the march of time, disguised as making a decision, driving an action.

Outside the window, I spot the sex workers across the street, walking back inside the strip club, putting their arms around each other. There is also a part of me, long buried, deeper down, a wild, undomesticated self that wasn't trained, a self that was bossy, opinionated, and furiously clung to anything I could control in an uncontrollable world. This side of me is always eager to burn it all down. No, I don't want to be remembered as the woman who played the game, who bent under pressure to a bunch of wealthy tech bros, who designed a cemetery theme park that made bank off of peoples' mourning.

I place my fingertips on the table. My hands feel cold and numb. I can't imagine losing him, again. There are so many things that I want to tell him about my career, about how technology has developed and changed since he's been gone. I swivel his image to the left then the right. How strange that I can modify him now, play God in this position. My grandfather doesn't belong here. He shouldn't have to live on this table. I swallow, hard. In fact, he doesn't live on this table at all. He lives on in my memories, which belong solely to me. I place my hand at the top right corner of the digital table and look up into Phil's grinning face. I click "Delete."

THAÏS MILLER is the author of the novel *Our Machinery* (2008) and the short story collection *The Subconscious Mutiny and Other Stories* (2009). She is a Ph.D. candidate in literature, pursuing a creative/critical writing concentration, at the University of California, Santa Cruz, where she also teaches creative writing and literature.

This Drug Can Mend a Broken Heart

A new therapy promises to take the sting out of traumatic memories

BY SHAYLA LOVE

ON VALENTINE'S DAY in 2016, Anne Lantoine received not flowers, but divorce papers. In the months preceding, she had been preparing for her family's move from France to Canada—or so she thought. She arrived in Quebec early with one of her three children, who was preparing to start college there, while the other two remained in Europe for school. Her husband stayed behind to manage the sale of their house in Marseille.

Then the realtors began to complain, through a barrage of calls and emails, to Lantoine. Her husband was not acting like a man who wanted his house sold. He wasn't answering phone calls and was never available for showings. In January 2016, Lantoine called him after yet another complaint from a realtor. The next morning, he sent her an email with a notice for a court hearing, and she discovered her husband had actually filed for divorce, without telling her, months earlier.

That February, she finally got the paperwork, not from her husband, but from her real estate agent. "It was not my last shock," Lantoine, now 59, recalls. "I also discovered that my husband's mistress was living in my home." These revelations were a huge blow practically: It disrupted the immigration paperwork, and Lantoine and her daughter lost their visa applications. But the searing pain was in the betrayal and deceit.

"I became very anxious and had constant nightmares," she says. "I was tired all the time and had panic attacks each time I opened my mail or my emails, or when I had an unidentified phone call."

Though the details of each case vary, romantic betrayal through infidelity, abandonment, or emotional manipulation can upend one's life in an instant. For Lantoine, her future plans, and the person they were attached to, were suddenly gone, and her functioning along with them.

GRAPHICS MASTER / SHUTTERSTOCK

"It doesn't erase what happened to you. It just changes the impact it has on your life."

Exhausted and an emotional wreck after almost a year, Lantoine learned about a clinical trial at the Douglas Mental Health University Institute, a Canadian psychiatric hospital in Montreal, that sought to ease the pain of romantic betrayal. The study did not rely on traditional psychotherapy sessions. It claimed it would dampen the emotional reverberations of what happened to her by pairing a beta-blocker medication called propranolol with a series of "memory reactivation sessions." She signed up.

It sounds like science fiction, or science romantic-fiction. The 2004 movie *Eternal Sunshine of the Spotless Mind* often gets brought up, says Michelle Lonergan, now a postdoctoral fellow at the University of Ottawa who led the trial as part of her Ph.D. In the film, a couple, post-breakup, use a service to erase their memories of one another in response to the suffering of heartbreak.

But the experiments that Lantoine enrolled in were an attempt to use a very real feature of the brain—albeit one we're still learning the ins and outs of—called memory reconsolidation to attenuate agonizing romantic memories.

"Memory reconsolidation" describes how, when we recall a memory, it can become pliable. There is hope—and some intriguing early data—that, at the moment of recollection, we might be able to intentionally change a memory and make it less burdensome. This ability to modulate distressing memories is being investigated as an intervention to treat post-traumatic stress disorder,[1] addiction,[2] phobias,[3] and is thought to have promise for depression or anxiety more broadly. It rests on an idea that's emerged from our understanding of memory over the past few decades: Memories are not fixed, even the ones that haunt us the most.

Described in the *Journal of Affective Disorders* in 2022, the study Lantoine enrolled in is the first application of a memory reconsolidation-focused treatment for adjustment disorder resulting from romantic betrayal.[4] (Adjustment disorder is defined as an emotional and behavioral maladaptive reaction to a stressful event, but not a life threatening one, so it doesn't meet criteria for PTSD.)

Unlike *Eternal Sunshine*, Lantoine's memories didn't vanish in a dramatic collapse of a beach house into the Montauk coastline. She still had the declarative memory of what had happened.[5] But, as Lantoine describes it, the memories were no longer debilitating.

"The treatment doesn't remove the remembrance of the events," Lantoine says. "It just removes the pain that was associated with the events. It doesn't erase what happened to you. It just changes the impact it has on your life."

WHEN A MEMORY INITIALLY FORMS, or is consolidated, it relies on chemical interactions between neurons in our brain. When a memory is remembered, or retrieved, it can be momentarily destabilized while those same chemical processes reconsolidate the memory.

"We feel that our memories, whether they're conscious or unconscious memories that influence our behavior, are fixed and rooted in fact," says Joff Lee, a professor of memory neuroscience at the University of Birmingham who was not involved in the trial. "But actually, pretty much everything that we know about memory suggests that these memories are malleable, and they change for potentially good reasons."

When presented with new information, it's helpful for our memories to be able to update so that we can learn and adapt to our surroundings. By hijacking this feature, researchers have shown in animal models that when memories become labile, it's possible to intervene.

"Visualize a monster, with big long claws, digging deep into your heart, ripping your heart out while you are still breathing."

More than 50 years ago, scientists found they could induce something called "post-retrieval amnesia."[6] Rats could forget a fear response if given an electroconvulsive shock at just the right time to interrupt the reconsolidation of that memory. The study was one of the first to challenge the idea that memories, once formed, were unchanging. There are now dozens of animal studies that show that when drugs are given to block the molecules needed for memory consolidation, memories seem to vanish, even when those memories aren't new.[7]

It soon became clear that memory reconsolidation could be a powerful therapeutic tool. But the methods used in animal studies to interfere with reconsolidating were often harmful to humans. Enter propranolol: a common beta blocker used for lowering blood pressure as well as for treating anxiety and preventing migraines. Propranolol impairs adrenaline hormones in the brain and is thought to impact the production of other molecules needed for memory reconsolidation.

Starting in the early 2000s, researchers showed that, in rats, the drug could have similar post-retrieval effects as the more toxic compounds. And in 2009, researchers found that propranolol could help people disengage from a learned fear response.[8] In this study, scientists showed human participants images of spiders, paired with an electric shock. One day later, some were given propranolol and others a placebo. On the third day, when participants saw the same images, those who had received the placebo noticeably startled, a physical manifestation of the fear response usually paired with a negative emotional state. But those who had been given the propranolol no longer had that reaction. These participants could still remember what had happened to them; propranolol didn't erase the facts. But they no longer exhibited the biological signs of being afraid.

Researchers soon began applying these findings to try to treat severe conditions, such as PTSD. Alain Brunet, a psychologist and researcher at the Douglas Institute and McGill University, and senior author of the study Lantoine participated in, described in a 2018 paper that people with PTSD who took propranolol and received six 25-minute trauma reactivation sessions had fewer PTSD symptoms compared to a group that underwent the same sessions paired with a placebo. (He has even trademarked "Reconsolidation Therapy," and the "Brunet Method," which describe the protocol of pairing propranolol with memory retrieval sessions.)

Brunet has long felt that reconsolidation therapy could have wider appeal. "We wanted to broaden the uses of reconsolidation therapy," Brunet says. So he and his team went looking for people suffering from an unfortunately common adjustment disorder—that spurred by romantic betrayal.

Even if we can change memories, should we?

ANNE LANTOINE WAS of course not alone in suffering heartbreak in Quebec. Brunet and Lonergan recruited 61 people in total who were cheated on, abandoned, wiped out financially, "all kinds of horrendous stories," Lonergan says.

The participants described being unable to sleep, gaining or losing weight, starting smoking, losing their hair, and suffering from nosebleeds. "It hurts everywhere!" as one 44-year-old woman described in a follow-up qualitative paper from the research team.[9] "Your throat hurts. You can't breathe. When you think about it you hurt ... You have these really graphic images, and you can't block them, there's nothing you can do. It's in your face all the time." A 44-year-old man described his intrusive thoughts replaying "like a movie all the time."

Being reminded of their former partners was especially distressing, like the anniversaries of when they discovered they were being cheated on, seeing photos of them online, or even seeing people who walked or talked like their former partners.

"When I really knew that he had betrayed me, the pain, and the torture it was like I had been cut off at my knees ... if you want to visualize you know like some sort of monster, with big long claws, and just digging deep into your heart, ripping your heart out while you are still breathing and alive and very conscious, and taking a bite out of your heart right in front of your face, that's what it feels like," a 50-year-old woman said.

In the trial, there was first a four-week waiting period when no one got any treatment. This limbo served as the control condition against which to compare the treatment. Then each person wrote a narrative of their betrayal, in as much detail as possible. In five memory reactivation sessions, they read their own descriptions one hour after taking propranolol. Compared to the waiting-period, the researchers found there was an overall significant reduction in symptoms, including intrusive thoughts, avoidance, and hypervigilance, as well as a decrease in anxiety and depression, starting after the first session. Up to four months later, those benefits remained.

"They were really in trouble," Lonergan says. "And so we offered them treatment. And luckily, for a good chunk of them, it really seemed to work."

THE MEMORY RECONSOLIDATION THEORY tells a tidy story about how practitioners might be able to help people, at least emotionally, rewrite their narratives. But does it tell the full story?

Lonergan acknowledges that there might be other factors at play. For example, the empathetic support in the retrieval sessions could have played a role in participants' improvements, and she hopes to do future work on adjustment disorder and romantic betrayal with a full placebo group, the way the PTSD trial ran.

Lee thinks we should also have some humility about which mechanisms these therapies might be

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COMFORTABLY NUMB
When a memory is remembered, or retrieved, it can be momentarily destabilized with a drug therapy, numbing its emotional pain.

tapping into. Memory reconsolidation is likely a complex process that co-occurs with many other cognitive and neurobiological systems.

This is underscored by the fact that results of reconsolidation therapies have not always been consistent.[10,11] Several studies have failed to replicate,[7] and some even found reconsolidation attempts can lead to adverse events.[12,13] A randomized, double-blind placebo-controlled study in smokers from 2015 didn't find any effect on physical reaction after being given a dose of propranolol.[14] Three other placebo-controlled studies in people with PTSD also didn't show any reduced symptoms.[15]

There could be rules and caveats to using memory reconsolidation as an effective tool that we simply don't understand yet. Other research into memory reconsolidation has found, for example, that updating an existing memory is most effective when the brain gets just enough new information, such as a new stimulus in place of an old one that had triggered

If just the facts of a memory remain, can we really say it's the same?

fear or loathing.[16,17] If the new information introduced is too strong, a *new* memory might be created instead of an alteration to the older memory, and the two memories will compete. "Those are all technical things that people are still figuring out," Lonergan says.

Nevertheless, given its promise, attempting to use memory reconsolidation in therapeutic interventions seems obvious to Brunet. If we know that sometimes memories are malleable, why *wouldn't* we try to target that, he says?

BUT EVEN IF WE *can* change memories, *should* we?

Memory researchers Tom Beckers and Merel Kindt raised this point in a 2017 review.[7] "Concerns have been voiced as to how desirable of a therapeutic goal it is to make people forget about significant events that have happened in their personal lives and that may play a central role in defining who they are," they wrote.

Is it okay if just emotional parts of memory are being stripped away, as long as the declarative elements remain?

In his 19th-century essay, "What Is an Emotion," psychologist William James challenges us to try to imagine an experience of emotion, like anger, without the elements of a racing heart or flushed face. If just the facts of a memory remain, can we really say it's the same, once it's been neutered of its emotionality?

But that's somewhat the point, Lonergan says. The people in the study were not able to move on or find peace after what happened to them. Emotional memories are not sequestered to the mind. These individuals needed the intensity of the emotions dialed down so that they could sleep, eat, and resume normal day to day functioning. "We're not specifically targeting and removing them from people's brains—they still remember what happened," she says. "But instead of being a traumatic memory, it's just a bad memory."

Further, our ability to update and modify our memory is built into us—whether aided by a drug or not. Other forms of psychotherapy similarly seek to change our relationship to and framing of our memories. The goal of a targeted, pharmaceutical intervention would be to achieve that result by way of going after the memory directly.

Lantoine says, five years out, she still feels the positive effects from the treatment. It was an improvement that came after about the third reactivation session. The daily torment she had felt receded into the background.

"It's like a chronic pain you get rid of," she says. "A bit like the scars I have on my knee and on my hip: I can see them, I remember I got them after painful surgeries. I remember I felt this pain. But *they* are not painful anymore. Those events have left scars in my brain," she says of her experience of betrayal. "It's impossible to forget what happened and to erase those scars. But they don't hurt."

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ChatGPT Is a Mirror of Our Times

What language AIs make up for in efficiency they lack in humanity

BY PHILIP BALL

COMPUTERS AND INFORMATION TECHNOLOGIES were once hailed as a revolution in education. Their benefits are undeniable. They can provide students with far more information than a mere textbook. They can make educational resources more flexible, tailored to individual needs, and they can render interactions between students, parents, and teachers fast and convenient. And what would schools have done during the pandemic lockdowns without video conferencing?

The advent of AI chatbots and large language models such as OpenAI's ChatGPT, launched in November 2022, create even more new opportunities. They can give students practice questions and answers as well as feedback, and assess their work, lightening the load on teachers. Their interactive nature is more motivating to students than the imprecise and often confusing information dumps elicited by Google searches, and they can address specific questions.

But large language models "should worry English teachers," too, Jennifer Rowsell, professor of digital literacy at the University of Sheffield in England, tells me. ChatGPT can write a decent essay for the lazy student. It doesn't just find and copy an essay from the web, but constructs it de novo—and, if you wish, will give you another, and another, until you're happy with it. Some teachers admit that the results are often good enough to get a strong grade. In a *New York Times* article, one university professor attests to having caught a student who produced a philosophy essay this way—the best in the class. High school humanities teacher Daniel Herman writes in *The Atlantic* that, "My life—and the lives of thousands of other teachers and professors, tutors and administrators—is about to drastically change." He thinks that ChatGPT will exact a "heavy toll" on the current system of education.

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Schools are already fighting a rearguard action. New York City's education department plans to ban ChatGPT in its public schools, although that won't stop students using it at home. Dan Lewer, a social studies teacher at a public school, suggests on TikTok that teachers require students submitting from home also to provide a short video that restates their thesis and evidence: This, Lewer says, should ensure "that they are really learning the material, not just finding something online and turning it in."

OpenAI's researchers are themselves working on schemes to "watermark" ChatGPT's output; for example, by having it select words with a hidden statistical signature. How easy it will be for harried teachers to check a class-load of essays this way is less clear—and the method might be undermined by "translating" ChatGPT's output by running it through some other language-learning software. In a digital arms race of cheating student against teacher, I wouldn't count on the teacher being able to stay ahead of the game. Some are already concluding that the out-of-class essay assignment is now dead.

But the challenge posed by ChatGPT isn't just about catching cheats. The fact that AI can now produce better essays than many students without a smidgeon of genuine thought or understanding ought to prompt some reflection of what it is that we aim to teach in the first place. Herman says it is no longer obvious to him that teenagers will need to develop the basic skill of writing well—in which case, he says, the question for the teacher becomes, "Is this still worth doing?"

Without wishing to detract from the impressive algorithmic engineering, ChatGPT is able to generate more-than-passable essays not because it is so clever but because the route to its goal is so well-defined. Is that a good thing in the first place? Many education experts have long felt a need change the way English is taught, says Rowsell, but she admits that "teachers are finding it very difficult to make a substantial change from what we've known so long. We simply don't know how to teach otherwise."

Language AI might force matters to a head. "Science has leapt ahead, and we [in literacy education] don't know quite how to grapple with it," says Rowsell. "But we've learned that we don't fight this stuff—let's understand it and work with it. There's no reason why classical essay-writing and ChatGPT can't work together. Maybe this will catalyse the change we have to make within teaching." If so, it should start with a consideration of what language is for.

The algorithm has no sense that "love" and "embrace" are semantically related.

ALGORITHMS THAT CAN INTERACT using natural language have been around since the earliest days of AI. Computer scientist Joseph Weizenbaum of MIT recounted how, in the 1960s, one of his colleagues ended up in an angry remote exchange with such a program called Eliza, thinking he was in fact conversing with Weizenbaum himself in a particularly perverse mood.

That such a crude language program as Eliza could fool a user reveals how innately inclined we are to attribute mind where it does not reside. Even until recently, language-using algorithms tended to deliver little more than awkward phrases full of non-sequiturs and solecisms. But advances in the technology—the exponential growth in computational power, the appearance of "deep-learning" methods in the mid-2010s, an ever-expanding body of online data to mine—have now produced systems with near-flawless syntax that supply a spooky simulacrum of intelligence. ChatGPT has been hailed as a game changer. It can perform all manner of parlour tricks, like blending sources and genres: a recipe for fish pie in the style of the King James Bible, or a limerick about Albert Einstein and Niels Bohr's arguments over quantum mechanics.

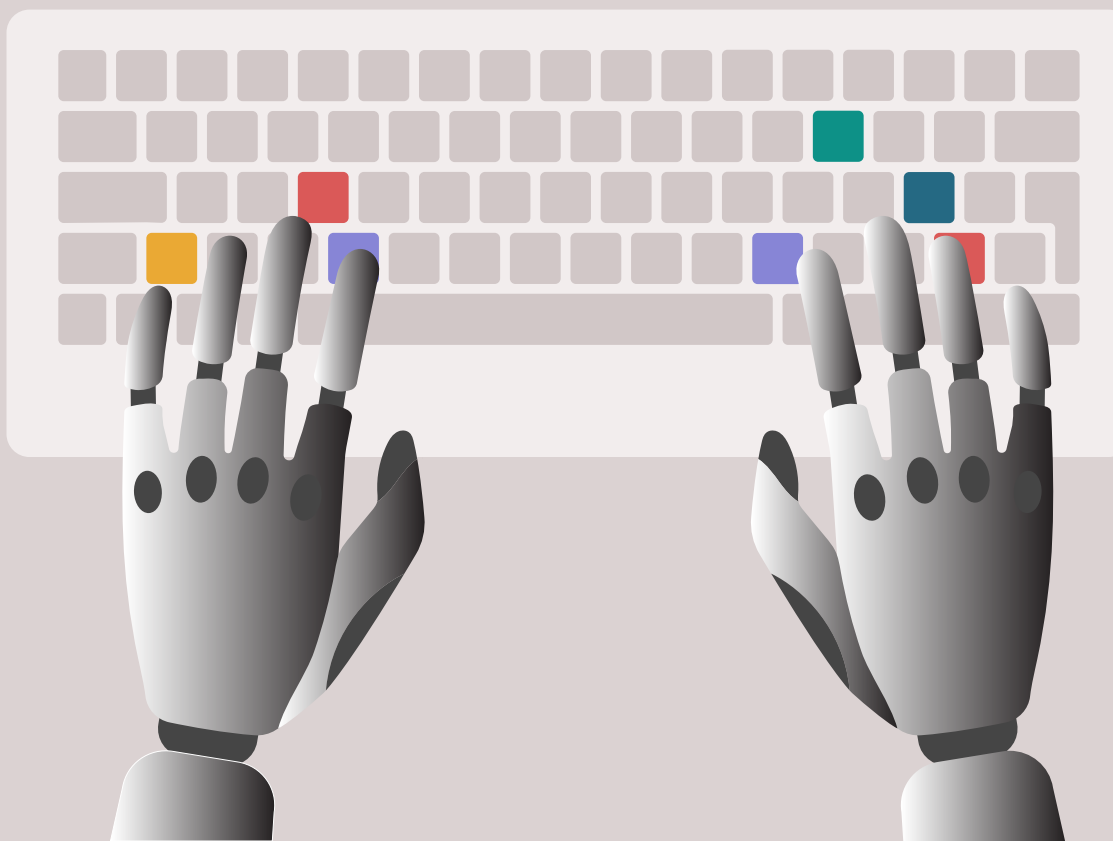
There are evident dangers in these large language model technologies. We have little experience in dealing with an information resource that so powerfully mimics thought while possessing none. The algorithm's blandly authoritative tone can be harnessed for almost any use or abuse, auto-generating superficially persuasive screeds of bullshit (or rather, repackaging in an apparently "objective" and better-mannered format the ones that humans have generated).

The algorithm is ultimately still rather "lazy," too. When I gave it the essay assignment of summarizing the plot of *Frankenstein* from a feminist perspective, ChatGPT did not seem to have consulted the vast body of scholarship on that issue, but instead provided a series of stilted and clichéd tropes barely connected to the novel: It "can be seen as a commentary on the patriarchal society of the time," and "the ways in which women are often judged and valued based on their appearance." It would probably say the same about *Pride and Prejudice*.

Some of these flaws might be avoided by giving the large language models better prompts—although to get a really sharp, informed response, the user might need to know so much that writing the essay would pose no challenge anyway. But at root the shortcomings here reflect the fact that the algorithm is not tracking down the feminist literature on *Frankenstein* at all, but is simply seeking the words and phrases that have the highest probability of being associated with those in my prompt. Like all deep-learning AI, it mines the available database (here, texts "scraped" from online sources) for correlations and patterns. If you ask it for a love sonnet, you are likely to get more words like "forever," "heart," and "embrace" than "screwdriver" (unless you ask for a sonnet about a screwdriver, and yes, I admit I just did that; the result wasn't pretty). The algorithm has no sense that "love" and "embrace" are semantically related. What is so impressive about ChatGPT is how it is able not just to smooth out the syntax in these word associations but also to create context. I think it's unlikely that, "You are the screw that keeps me firmly braced," is a line that has ever appeared in a human-composed sonnet (and for good reason)—but still I'm impressed that you can see what it is driving at. (ChatGPT can do puns, too, although I take the blame for that one.)

For factual prompts, the texts that emerge from this probabilistic melange generally express consensus truths. This guarantees the exclusion of any particularly controversial viewpoints, because by definition they will be controversial only if they are not the consensus. Asking a large language model who killed JFK will deliver Lee Harvey Oswald. But ChatGPT occasionally invents random falsehoods, too. In its biography of me, it knocked two years off my age (I'm OK with that) and gave me a fictitious earlier career in the pharmaceutical industry (just weird).

If ChatGPT churns out a credible school essay, it's because we are setting school pupils an equivalent task: Give us the generally agreed facts, with some semblance of coherence. Student essay-writing already tends to be formulaic to an almost algorithmic degree, codified in acronyms: Point-Evidence-Explanation-Link, Point-Evidence-Analysis-Context. Not only are students told exactly what to put where, but they risk having marks deducted if they deviate from the template. Current education rewards an ability to argue along predictable lines. There's some logic in that, much as art students are sent off to galleries to draw and paint copies of great works, learning the skills without the burdensome and unrealistic demand of having to be original.



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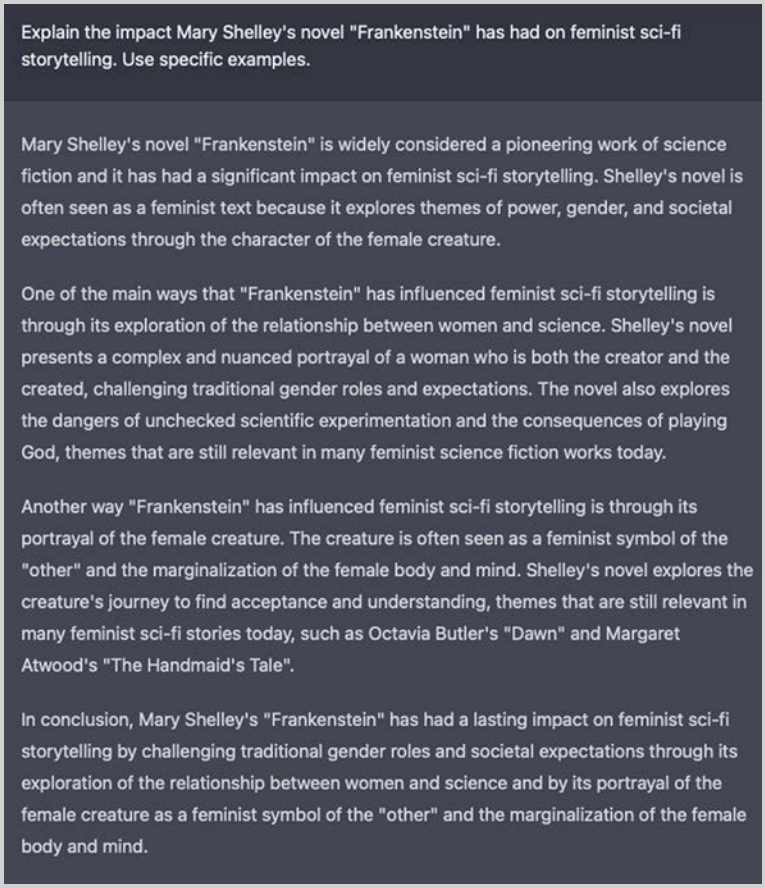

A CHEAT'S BEST FRIEND? Give ChatGPT an essay prompt, like how Mary Shelley's *Frankenstein* influenced feminist sci-fi storytelling, and it will provide a student with at least a starting point for a school assignment. Continue prompting it, and you could complete the essay.

But is this *all* we want? Rowsell says it is hard for teachers or educationalists even to confront the question, since the cogs of education systems typically continue to turn merely on the basis that "this is how we've always done it." A deep dive into the teaching of cursive handwriting, for example, reveals that there is no clear justification for it beyond tradition. But maybe now's the right time to be asking this difficult question.

My instinct as an occasional educator—in the 1980s I used to teach computer classes in a prison, and I homeschooled my children for a time—is that of the scientist, I suppose: to start with an explanation of how a thing works, starting with its parts. "You won't use it well unless you understand it first!" says my inner voice. But while I listed off unfamiliar computer components to my incarcerated pupils, one finally chimed in, "I don't even know how to turn it on!"

I appreciate that sometimes schoolchildren must feel toward English instruction somewhat as my prison class did to computers, being told the unfamiliar names of the components (noun, embedded clause, fronted adverbial; CPU, RAM, bits and bytes) while thinking, "But I just want to know how to use it!" But ChatGPT seems to make all that groundwork otiose, much as your average computer user needs to know nothing of coding or shift registers. English writing? There's an app for that. High-school humanities teacher Herman worries that students might be inclined to depend on language AI for all their writing needs, just as many will now consider it a waste of time to learn a foreign language in the age of real-time fluent translation AI.

If ChatGPT churns out a credible essay, it's because schools set an equivalent task.

I realize now that I was teaching prisoners about the inner workings of computers because I loved all that stuff. I suspect few if any of them loved it, too—but they rightly discerned that an ability to use a computer was going to become important in their life. I want my kids to love the way language works and what it can do, too. But they need first to know how to turn it on, so to speak. And the on-switch for language is not the distinction between nouns and verbs or the placement of subclauses, but the more fundamental process of *communicating*.

When we learn good use of language, we are not simply being trained to conform to a model. Those templates for sentence or essay construction do not follow some law of literature demanding particular arrangements of words, phrases, and arguments. However crude and formulaic they might be, ultimately they exist because they benefit the reader. In other words, reading is a cognitive process with its own dynamics, which the writer can facilitate or hinder. Sometimes all it takes to transform a confusing sentence into a lucid one is the movement of a single word to where it matches the cognitive processing of the reader. There is nothing esoteric about this; good communication is a skill that can be learned like punctuation. (And punctuation itself exists to aid good communication.)

What all this demands is empathy: an ability of the writer to step outside their head and into the reader's. For factual text, the goal is usually clarity of expression. For fiction, the priority might be elsewhere: even, indeed, to impede instant understanding, not arbitrarily or perversely but in order to deliver a little jolt of surprise and delight when the meaning crystallizes in the reader's mind. Music does the same with melody and rhythm, and this is partly how it moves and excites us. Shakespeare is famous for his sentence-inversions: a rearrangement of the usual order ("But soft, what light through yonder window breaks?") to arrest the mind for a moment, perhaps for emphasis, perhaps for the sheer thrill of the lexical puzzle. On the larger scale, much of fiction is the art of controlled disclosure, of revealing information at the right moment and not sooner (or later).

Language is, at its heart, a link between minds. One theory of the origin of language, proposed by linguist Daniel Dor, argues that it arose not for simple communication but for "the instruction of the imagination."

The question for the teacher becomes, "Is this still worth doing?"

It enabled us to move beyond the blank imperatives and warnings of animal vocalizations, and project the contents of one mind into another.

What does this imply for language AI? Precisely because the algorithm of a large language model does not have a communicative goal—it has no notion at all of what communication is, or of having an audience—it does not show us what language can do, and indeed was *invented* to do. It would iron out Shakespeare's quirky acts of linguistic subterfuge. It would fail to capture the rhetorical tools with which a good historian makes her case memorable and persuasive. And it is hard to see how a language model could ever truly innovate, for that is antithetical to what it is designed to do, which is simply to ape, mimic, and, as a statistician would put it, regress to the mean, which tends toward the mind-numbingly drab.

Language use is the opposite of that, and nowhere more so than among young people, whose stylistic invention in speech and digital discourse is enormous and even rather joyous. Progressive educationalists long to tap into the multimodality of the online sphere, but are struggling to figure out how. Crucially, the media-savvy communicative sophistication of Gen Z relies on the assumption of shared concepts, standards, and points of reference, just as much as does the compact and stylized language of a Tang-dynasty poem. If space is made in education for this facet of language use, it may well be immune to colonization by AI.

THERE'S NO DENYING that large language models raise a host of ethical and legal issues. So did the internet, and so do many other forms of deep-learning AI,

The on-switch for language is not the distinction between nouns and verbs or the placement of subclauses.

such as deep fakes and face recognition. We grapple with these problems and learn to live with them. Some believe that, panic about AI-based essay writing aside, large language models will eventually become just another tool, perhaps situated somewhere between the humdrum utilitarianism of Excel spreadsheets and the creative possibilities of digital photography.

After all, written language is itself often a tool, a means to an end. This doesn't mean we need to learn to use it only crudely. But it does mean that what the likes of ChatGPT can now offer is not only adequate for certain purposes but might even be valuable. People who struggle with literacy skills are already using ChatGPT to improve their letters of job application or their email correspondence. Some scientists are even using it to burnish their papers before submission. Arguably these AIs can democratize language in the way music software has democratized music-making. For those with limited English-language skills who need to write professionally, the technology could be a great leveler.

And just as electronic calculators freed up students' time and mental space once monopolized by having to learn logarithms for complicated multiplication, large language models might liberate pupils from having to master the nuances of spelling, syntax, and punctuation so that they can focus on the tasks of constructing a good argument or developing rhythm and variety in their sentences.

The absence of imagination, style, and flair meanwhile makes large language models no threat to fiction writers: "It's the aesthetic dimension of writing that is really hard for an AI to emulate," says Rowsell. But that is just what could make them an important new tool.

For example, I suspect it would help students see what makes a story or an essay come alive to get them to *improve* on ChatGPT's dull output. Perhaps in much the same way that some musicians are using music-generating AI as a source of copious raw material, large language models might provide kernels of ideas that writers can sift, select, and work on.

Here, as elsewhere, AI holds up a mirror to ourselves, revealing in its shortcomings what cannot be automated and algorithmized: in other words, what constitutes the core of humanity.

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The Iceberg Cowboys Who Wrangle the Purest Water on Earth

My journey to meet the people herding frozen leviathans on the maritime frontier

BY MATTHEW BIRKHOLD

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FOR MOST OF THE YEAR, Iceberg Alley is gray and cold. The largest city on its shores, St. John's, is known as "Canada's Weather Champion." Among major Canadian cities, the capital of Newfoundland and Labrador is the snowiest, windiest, wettest, and cloudiest, enjoying fewer than 1,500 hours of sunshine each year. Seattle, for comparison, gets 2,200 hours of sun annually. St. John's is so overcast, the difference between it and Seattle is greater than that between Seattle and Tampa. But for a few months, from May to August, the sun breaks through the clouds and warms the freezing waves swirling off the coast.

In this brief window, when Newfoundland relishes nearly half of the sunshine it will absorb for the entire year, icebergs fill the Labrador Sea. The Arctic ice pack undergoes its seasonal melt and Baffin Bay thaws, allowing the frozen mountains to continue their journey toward the Atlantic. Most break off of glaciers on the west coast of Greenland—what glaciologists call "calving." Speakers of a variety of languages, from Afrikaans to Uzbek, use the same word to define the process, as if the icy masses are the living offspring of glaciers. In Albanian, Farsi, and Italian, it is even more explicit: Glaciers "give birth." Across cultures and languages, icebergs are conceptualized like wild cattle or horses roaming the maritime frontier in our rhetorical imagination. It is no wonder, then, that the International Ice Patrol and Canadian Ice Service describe the summertime influx of icebergs as an annual "migration."

The final stage of an iceberg's life is especially volatile and difficult to predict.

This is when iceberg cowboys head to sea. These rough-and-tumble mariners earn their living wrangling icebergs—sometimes to subdue and capture the leviathans, other times to herd the ice in new directions. They are undaunted by warnings issued by the International Ice Patrol. To that end, the brave seafarers make bad role models for academics interested in icebergs and ship captains navigating the North Atlantic. The iceberg cowboys, however, give us a hint of what it will take to harvest icebergs if we are ever going to use them to save the planet. They show us that these frozen beasts are not entirely unapproachable.

ONE MILLION YEARS AGO, when mastodons roamed the Atlantic Coastal Plain in what is today New London, Connecticut, it was snowing in Greenland. We know this because glaciologists have taken ice cores from the center of the country. Using a drill that cuts a circle around a central point, they extract long, skinny tubes of ice. The process can take years, especially in a place like Greenland, where the ice sheet is more than 2 miles thick and drilling can only be done during the summer. Back in the lab, the glaciologists then analyze the ice to identify the particulates and chemicals captured by the falling snow. Using this information, they are able to reconstruct past climates and determine local temperature, greenhouse gas concentrations, and volcanic and solar activity.

The Greenland ice sheet was likely first formed some 3 million years ago, but it has grown and shrunk as the planet has warmed and cooled. It currently stretches 1,500 miles long by 680 miles wide and covers 80 percent of Greenland. Because most of the ice sheet is ringed by mountains, glaciers that lie along the coast like Sermeq Kujalleq function as outlets through which ice and water from the ice sheet come gushing out. Like rivers, glaciers are constantly flowing, pushed forward by the weight of their own ice. Sermeq Kujalleq, also known as Jakobshavn Glacier, travels an average of 130 feet in 24 hours and calves more than 11 cubic miles of icebergs each year into the Ilulissat Icefjord. Owing to this constant growth and shrinking, the oldest remaining known ice in the Greenlandic ice sheet today dates from the Pleistocene epoch, 1 million years ago.

COURTESY OF FREEMAN RALPH

Glaciers form when snow builds up and is buried each year by more and more snow. To understand the process, it helps to think of the snowball fights you might have had as a child. At normal atmospheric pressure, ice melts at 32 degrees Fahrenheit. Adding pressure, however, can lower the temperature at which this transformation, or solid-to-liquid phase change as we're taught in chemistry class, occurs. Imagine

A BIG HAUL A team from C-Core, an organization offering scientific and technical services in Newfoundland, Canada, tows an iceberg in Iceberg Alley.

ICE HUNTER Ed Kean harvests icebergs in Newfoundland, Canada. Here he's using a wooden pole tipped with a metal hook to wrangle one aboard.

squeezing a fistful of powdery snow. The force of your clasp manages to melt the snow just a bit. When you open your fingers and release the pressure, the snow refreezes into a harder, more solid lump. During a snowball fight, you might repeat this process a few times, adding a bit more fresh snow to the ball in your hand each time, until you create the perfect ammunition. In Greenland during the Pleistocene epoch, as more and more snow piled up, the ice crystals were compressed and recrystallized over centuries, forming rock-hard, crystal-clear glaciers.

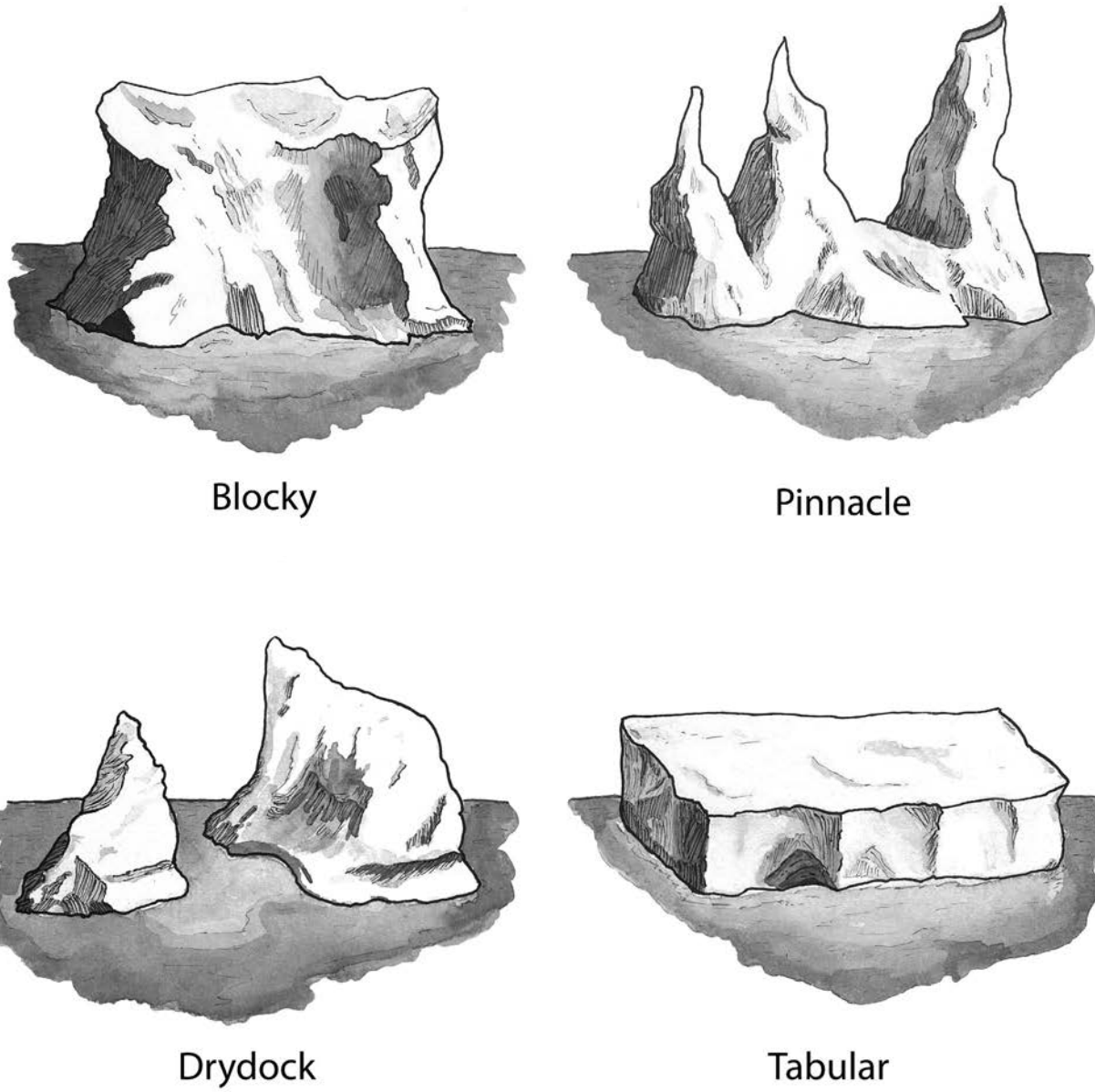
To get to this ancient ice, we don't always have to rely on glaciologists and their specialized drills. Instead, we can wait for icebergs to calve from glaciers and come to us; after all, they can travel thousands of miles before melting. For this reason, the famed Scottish geologist Charles Lyell believed icebergs transported boulders around the world. His dear friend Charles Darwin agreed, further suggesting that icebergs were responsible for the dispersion of species. While this theory has since been debunked, the 19th-century naturalists were correct that icebergs can act as transport vessels, bringing artifacts and stories from the past with them. In addition to chemicals and air bubbles trapped in snow, plants and animals can get caught on top of glaciers and become part of the historical record. Sometimes the findings are unbelievable. In the 19th century, several people reported seeing wooly mammoths frozen inside icebergs. Their shaggy hair and long, curled tusks were purportedly cryogenically preserved inside the ice. Another legend tells of a fully clad Viking encased in an iceberg, still gripping his spear and shield. Every time an iceberg floats by, an ancient piece of the past is carried along with it.

VERONIQUE DE VIGUERIE

Glaciologists talk about "singing" icebergs, too.

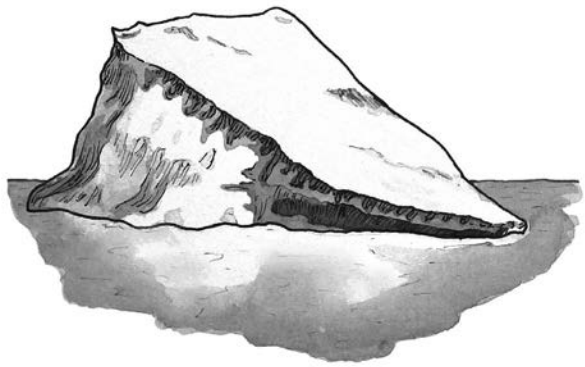
Iceberg ice is not just primeval; it is also pristine. As snowflakes cascade through the atmosphere, they can catch sundry gaseous and particulate matter thanks to their latticework structures. Snow falling today, for instance, might absorb black carbon, mercury, formaldehyde, pesticides, and vehicle exhaust. Some scientists consequently advise children not to eat snow in urban areas. Thousands of years ago, however, the same pollutants were not floating around our atmosphere, so ancient glacial ice is comparatively immaculate. It has far fewer parts per million of impurities than most tap waters contain today. When glaciers calve, this unpolluted ice is packaged in a tidy parcel and launched into the salty sea.

Once an Arctic iceberg calves, it will typically live for three to six years, depending on its size and the journey it takes. An iceberg headed to the equator will melt faster than one grounded near the poles. Cycles of thawing and refreezing further create crevasses within the iceberg that can cause a berg to crumble or explode and spawn further icebergs. The final stage of an iceberg's life is especially volatile and difficult to predict. Scientists struggle to precisely foresee the path an iceberg might follow since the shape and size of an iceberg, ocean currents, winds, and waves affect a berg's velocity. In Iceberg Alley, the average drift speed is about 0.5 mph, though some bergs zip along at more than 2 mph. At this point in their lives, Arctic icebergs are prone to capsizing since increased erosion over time results in a loss of stability. In an iceberg's death throes, as some glaciologists describe it, the blocks are also noisy. Icebergs groan and sputter as they break up over open water. Glaciologists talk about "singing" icebergs, too. When bergs scrape the seabed or rub against each other they can vibrate and emit chilling harmonic tremors, like running a finger around the rim of a wine glass. Perhaps it is to be expected that we talk about icebergs like they are alive. Iceberg cowboys try to capture these creatures as they migrate through Iceberg Alley, before they die and all that unspoiled freshwater mixes with the ocean.

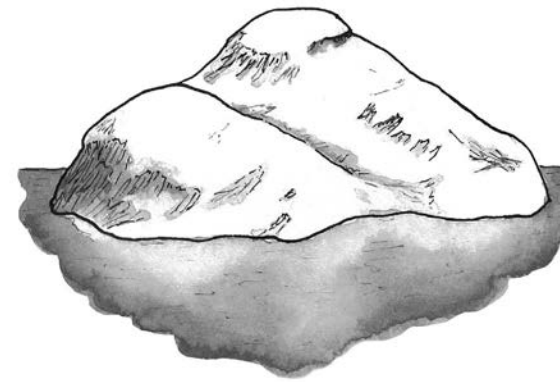


KNOW YOUR BERGS Glaciologists distinguish between six different types of iceberg, which is helpful because each type can have greater or lesser height-to-drift ratios and drift speed as a percentage of wind speed.

ESTELLE OLIVIA



Wedge



Dome

ED KEAN IS A FIFTH-GENERATION fisherman known abroad as "Captain Ahab of the Ice." To my ears, his speech sounds like the mix of a cheery Irishman and a grunting whaler too busy or too weary to open his mouth any wider. Despite Kean's easygoing attitude, he is acutely aware of the danger posed by icebergs that float in the waters off the coast of Newfoundland. Many calved from the very same glacier, Sermeq Kujalleq, that produced the frozen torpedo that sank the Titanic just 320 nautical miles away. But the risk is worth it to continue living off the sea. As the iceberg cowboy tells it, his family used to harvest ice from icebergs to cool fish that they brought up to the plants in Labrador. In the 1970s they had the ice tested at Memorial University of Newfoundland to ensure it was safe. In the process, they learned that it was exceptionally pure. In the 1990s Kean began harvesting ice commercially, and he has been at it ever since.

Icebergs "taste like water should taste," he explains. That's why they are worth wrangling. According to Kean, he and his wife drink several liters of iceberg water a day and his mother "will only drink iceberg water." In St. John's, when I tell people I'm interested in iceberg harvesting, they almost instantly reference Ed Kean, who is something of a celebrity here. The global COVID-19 pandemic spoiled my plan to sail with Kean, so I chat with him about icebergs while we're both standing on solid land. Proudly, the fisherman also directs me to videos online that document his work. By all accounts, it is arduous labor. Some years, Kean sells more than 1 million liters of the specialty water.

On days he harvests icebergs, which is almost every day in the short migration season, Kean is awake by dawn with a small crew. Using a satellite map, Kean identifies icebergs and motors his large fishing boat toward them. Once he sees the ice, he can select his approach. If the berg is grounded and sufficiently stable, he can carefully maneuver his accompanying barge, outfitted with a crane, near the ice. Then, using a hydraulic clamp attachment, he and his crew scoop up the ice and feed it into a large grinder on the ship. The ice is shredded and piped into storage tanks.

More commonly, the iceberg cowboy cannot get so close to the ice and harvesting looks a lot more like battling a wild animal. Because the ice can flip and roll unpredictably, Kean must approach cautiously. Plus, icebergs have treacherous underwater projections or "legs" Kean names them, that could damage his ship.

The frozen surface is not a static island, but an enormous, rock-hard reef.

Occasionally, his first move is to whip out a rifle. He shoots icebergs in hopes of splintering off a chunk. "Sometimes it works, sometimes it doesn't." Kean tells me that he is moving away from firearms now, though. The crew next leaves the big rusty rig behind and hops into a small motorboat to come near the ice. They circle the iceberg looking for smaller pieces that have broken off. Even these chunks can weigh more than a ton.

The next part comes right out of a rodeo. The cowboys use long wooden poles tipped with metal hooks to prod and jostle the ice closer to the boat. Once the iceberg is well positioned, the men fling a net over the ice and wrap it tight. The brute is then dragged back to the vessel, where a crane is lowered to affix a hook to the net. The ice is winched aboard and dropped onto the deck. The ice is rinsed, and now the backbreaking work begins. Using axes, the crew hacks into the ice, chipping it into smaller chunks. These are then shoveled into 1,000-liter plastic storage containers where they will melt. Kean says he has difficulty maintaining a crew for many seasons since the work is so difficult. Maybe I should be grateful that I don't have to participate in this rodeo.

Since I don't get the opportunity to play cowboy in St. John's, I decide to be a tourist instead. I board a ship from St. John's Port Authority to see an iceberg. If harvesting icebergs is like herding cattle, sightseeing for icebergs is itself a bit like being on safari. My tour operator even describes "hunting" for icebergs on the open sea. Our target is dangerous and unpredictable, capable of lashing out at any moment. For that reason, the provincial government of Newfoundland and Labrador has published viewing guidelines. We should keep a distance equal to the length of an iceberg or twice its height, whichever is greater. Anything within this perimeter is considered the "danger zone," in which viewers are exposed to falling ice, large waves, and submerged hazards.

As with lions and leopards, it can also be hard to tell where or when our mark might appear. "Who knows what nature is going to give us," my guide explains. Luckily, I get to see icebergs. The first we encounter rises out of the ocean like a smooth boulder. A cotillion of terns is settled at the peak of the dome's gentle curves, and for a moment, the ice seems passive and gentle. Then a wave crashes into the mass and I am reminded that the frozen surface is not a static island, but an enormous, peripatetic rock-hard reef. As the boat inches closer, I can see the slippery surface continue below the waves, stretching into the dark ocean. I am transported by the alien sight up close. The floating orb is like a puffy white flying saucer cutting through the water.

The next iceberg we spy is more spectacular, sparkling like a crystal castle in the bright sun. Two pinnacles, like turret-adored towers, loom 50 feet over our ship. They are connected with a low ice wall that reminds me of a crenelated parapet. I ask one of the guides if she thinks we can sail nearer. "That's up to the captain," she answers, "but he probably won't get closer because this berg isn't grounded." Salt water lashes the ice from every angle, like the ocean is a great artist carving a magnificent sculpture from a giant block. The ice dwarfs our boat even from our safe distance. When I finally look down, I am mesmerized by the aquamarine hue radiating from the submarine foundation. Intellectually, I know that around 90 percent of an iceberg's mass is hidden. But there is so much ice bobbing on the waves, I cannot fathom the true size of this creature.

Technically, I've seen a domed and a pinnacled iceberg. Glaciologists distinguish between six different types. The categories are helpful because different shaped bergs have greater or lesser height-to-drift ratios and drift speed as a percentage of wind speed. Some varieties are also more attractive for harvesting, depending on whom you ask. Domed icebergs are smooth and rounded on top. A blocky iceberg has a mostly flat top and steep vertical sides. Like the name implies, wedge icebergs have one thick end that tapers to a thin edge that disappears beneath the water. Pinnacled icebergs can be shaped like pyramids or consist of several spires that soar above the bulk of the mass. Similarly, dry-dock icebergs have two points like a giant letter U, the base of which is at water level so a boat could float on top of the berg between the towers. Lastly, a tabular iceberg has a flat surface because it usually calves from an ice sheet or shelf glacier. Most come from Antarctica, though some originate from Greenland and the ice caps of Arctic islands. These bergs can be many kilometers in length and width—far greater than the powerful ice I witness in Newfoundland.

Back on land, I head to raucous George Street to be "screeched-in." The cheeky local tradition begins with a supplication. I introduce myself and say I'd like to be a Newfoundlander. Next, I am meant to recite a vow. It is impenetrable to my daft ears, so I mumble along and jump to the next step, taking a shot of rum. It goes down easier than the final act: kissing a cod. I am again grateful the pandemic has changed my plans, since I get to peck the fish through a mask. I smooch the frozen cod and quickly order an Iceberg beer. Brewed up the street at Quidi Vidi Brewery, the smooth lager advertises itself as being "made with pure 20,000-year-old iceberg water." The beer is refreshing, but I cannot notice anything special about it. Admittedly, I am no connoisseur, and I've just had a fish in my face.

While I drink the beer, I think of Ed Kean. His sobriquet, Captain Ahab of the Ice, is unfitting. At the end of *Moby-Dick*, Herman Melville's fictional captain is drowned in his monomaniacal attempt to subdue the white whale. In St. John's, the lager in my hand is a sign of Kean's success. He has vanquished icebergs and lived to tell about it.

MATTHEW BIRKHOLD is an associate professor in the department of Germanic languages and literatures at The Ohio State University, and the author of *Chasing Icebergs: How Frozen Freshwater Can Save the Planet*. His writing has appeared in *The New York Times*, *The Atlantic*, *Foreign Affairs*, *The Washington Post*, *The Paris Review*, and *Indian Country Today*.

Excerpted from *Chasing Icebergs: How Frozen Freshwater Can Save the Planet* by Matthew Birkhold. Published by Pegasus Books, 2023.

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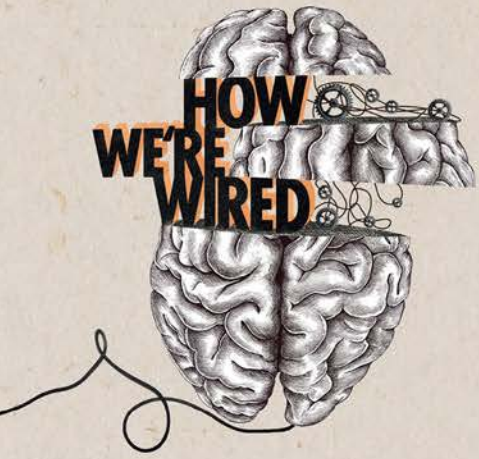

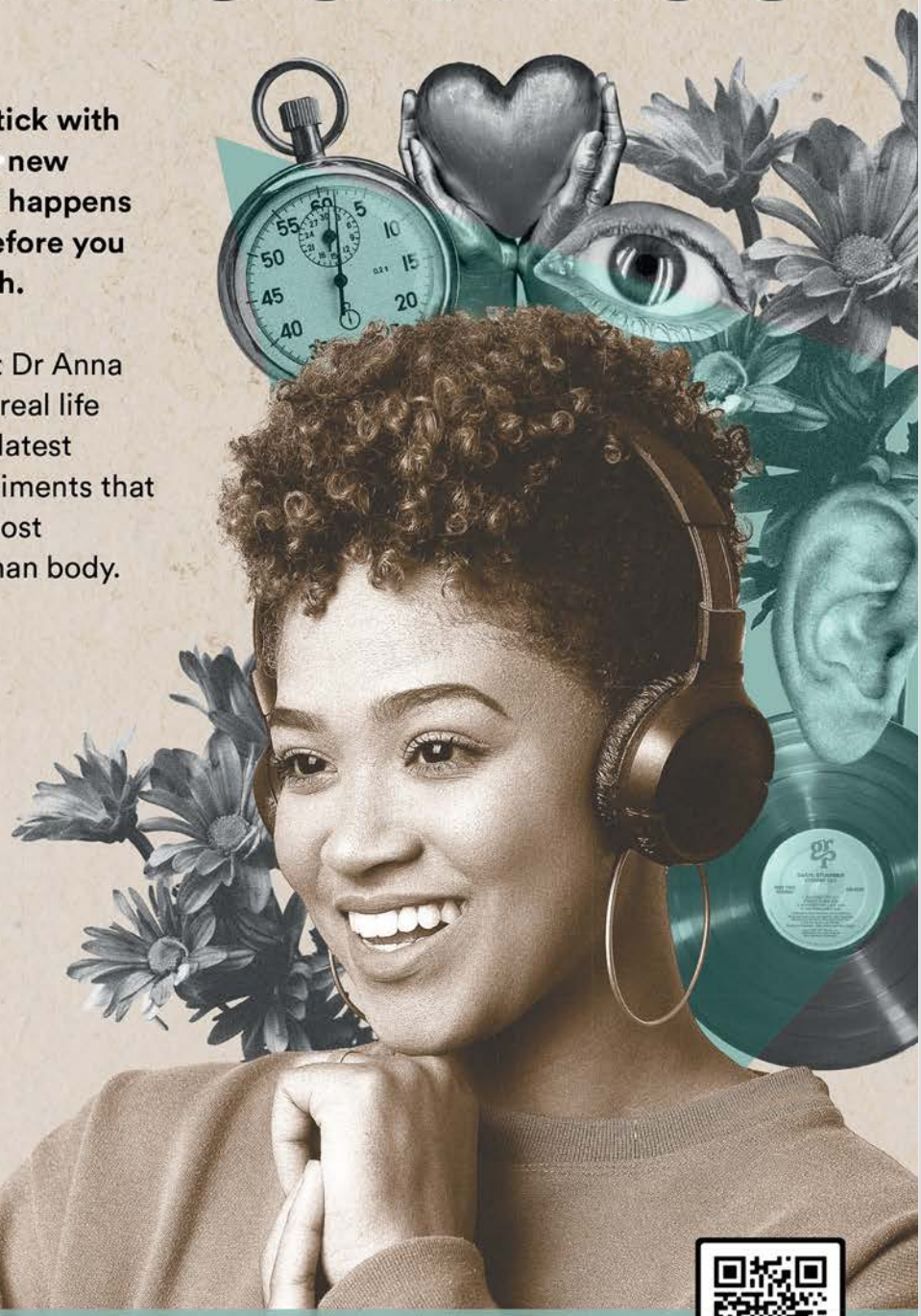

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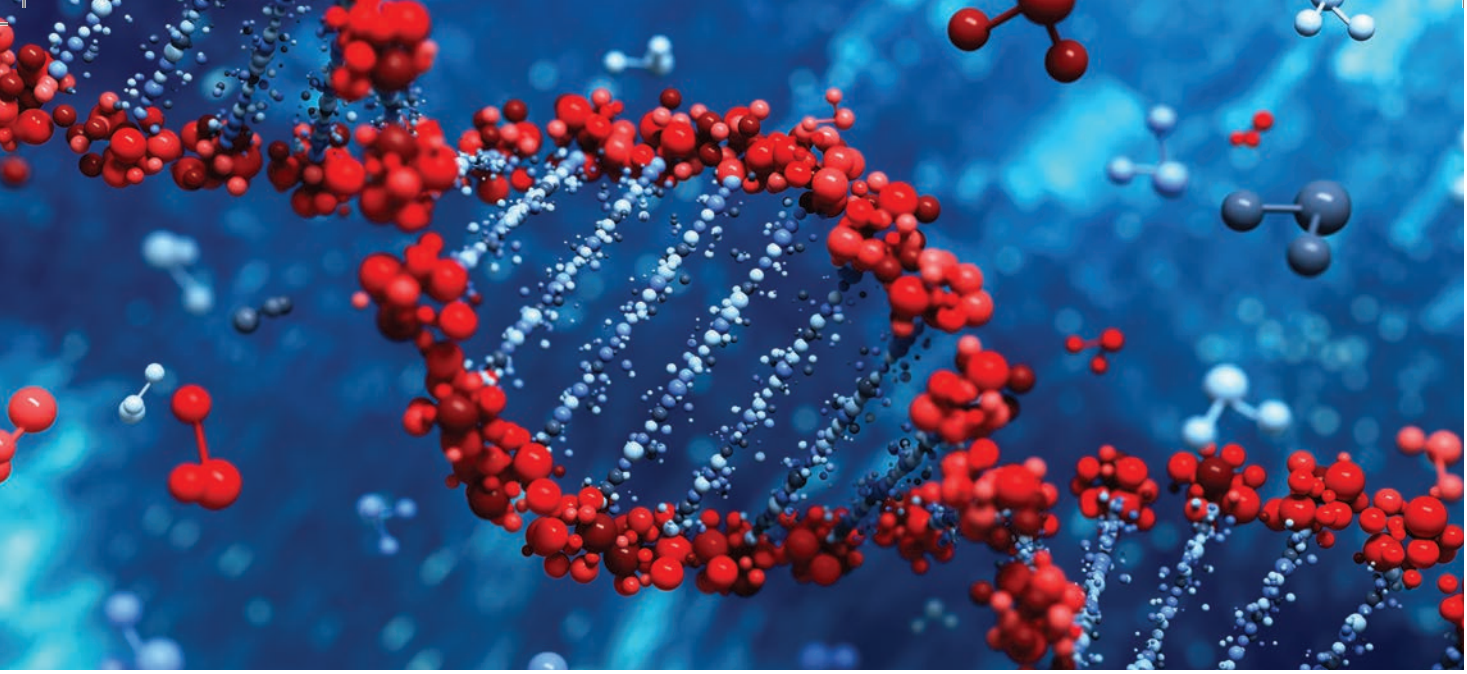

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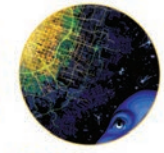

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Juli Berwald

The science writer and ocean expert on her fascination with marine life

INTERVIEW BY BRIAN GALLAGHER

FALLING FOR OCEAN SCIENCE

I grew up as far from any ocean as you can be in the continental United States. I didn't know anything about it. But my junior year of college, I went on a study abroad program to Israel. There's lots of water around there. I was actually pretty miserable because I didn't fit in very well. I was unhappy. I was eating too many pitas. But I saw a sign that said, "Marine Ecology Course: One Week in the Red Sea." I was like, "Sign me up. Get me out of here." We got on this five-hour bus ride and then these teachers threw snorkels and masks at us. Like, go get in the water. I put my head underwater, and saw these coral reefs. I thought: *How have I lived on this planet all these years and never knew that this existed?* It blew my mind. That whole week was life changing. I decided to study coral forever.

HAVING YOUR OWN RESTAURANT INSIDE YOU

Sediment is usually considered bad for coral because coral like clean, clear water. That's how they evolved to exist. Coral are animals—they're related to jellyfish and sea anemones. But they have this superpower, which are these algae that live in their tissues and photosynthesize. Those algae need sunlight, and therefore clear water. The reason why coral teamed up with the algae in the first place is because these clear waters don't have a lot of nutrients in them. But algae photosynthesize for the coral. They feed 90 percent of the sugar they make from photosynthesis straight to the coral. Some people have described it as like having your own restaurant inside of you. They basically have solar-powered systems inside of them that create energy for them.

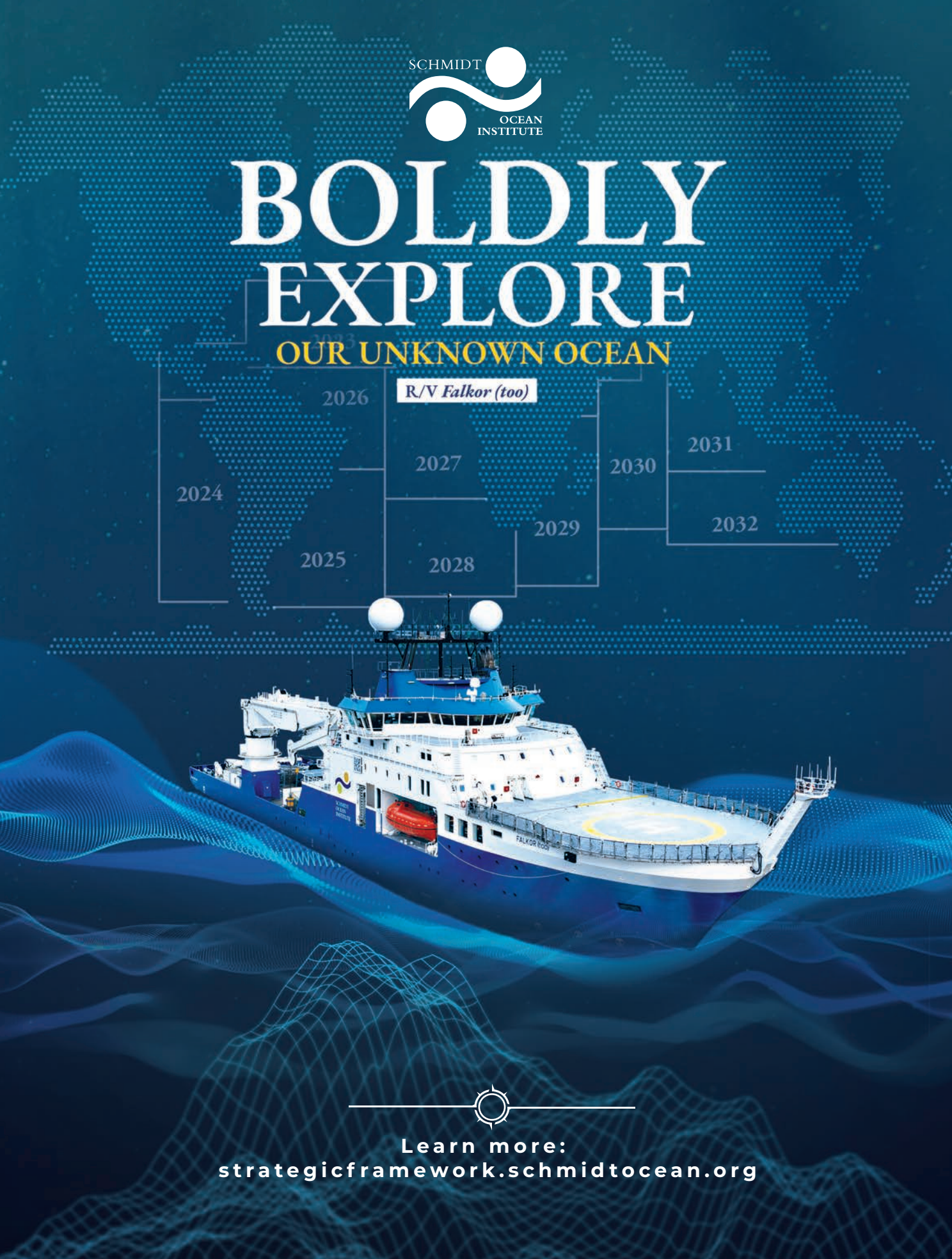
BEN FERN

STRANGE MARINE HEALTH

There's this strange lack of disease in Tela Bay, in Honduras. The Caribbean has been struck by many different diseases. In the 1980s, there was this incredible epidemic that just killed all of the sea urchins all over the Caribbean. And that's kind of the start of the end, for Caribbean coral reef health. Sea urchins are a keystone species on coral reefs because they eat macroalgae that can grow over the coral. But strangely in Tela there's sea urchins every foot or so—you'll see them all over the place. And there's a lack of coral disease in Tela Bay as well. But there's a really bad one raging through the Caribbean right now. It's called stony coral tissue loss disease. It melts the tissue off the coral, and it affects maybe two dozen species of coral in the Caribbean, which is about a third of the species. Most diseases we think of are very species specific. This one is not, and it's really ugly. It hasn't been seen on the reef yet in Tela. No one knows what the pathogen is.

BECOMING A SCIENCE WRITER

I got my Ph.D. in ocean science. In California, I worked on satellite imagery of the oceans. That was back when we were just getting these big overviews of what was happening out there. I was working on how much carbon dioxide the ocean takes up through photosynthesis, which was a big question at the time. Then I rolled off the academic path and ended up writing textbooks. That's where I really discovered that I love writing about science. I started writing little articles and press releases and things like that. Then eventually, I was like, "I gotta leave my mark here." So I wrote a book about jellyfish. And then recently I published a book about coral reefs, *Life on the Rocks*.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