NAUTILUS

WHAT WAR IS GOOD FOR
How conflicts advanced science

WE DREAM TO SOLVE PROBLEMS
The science behind sleeping on it

HOW WE'LL FIND ALIENS
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The Novel Machine

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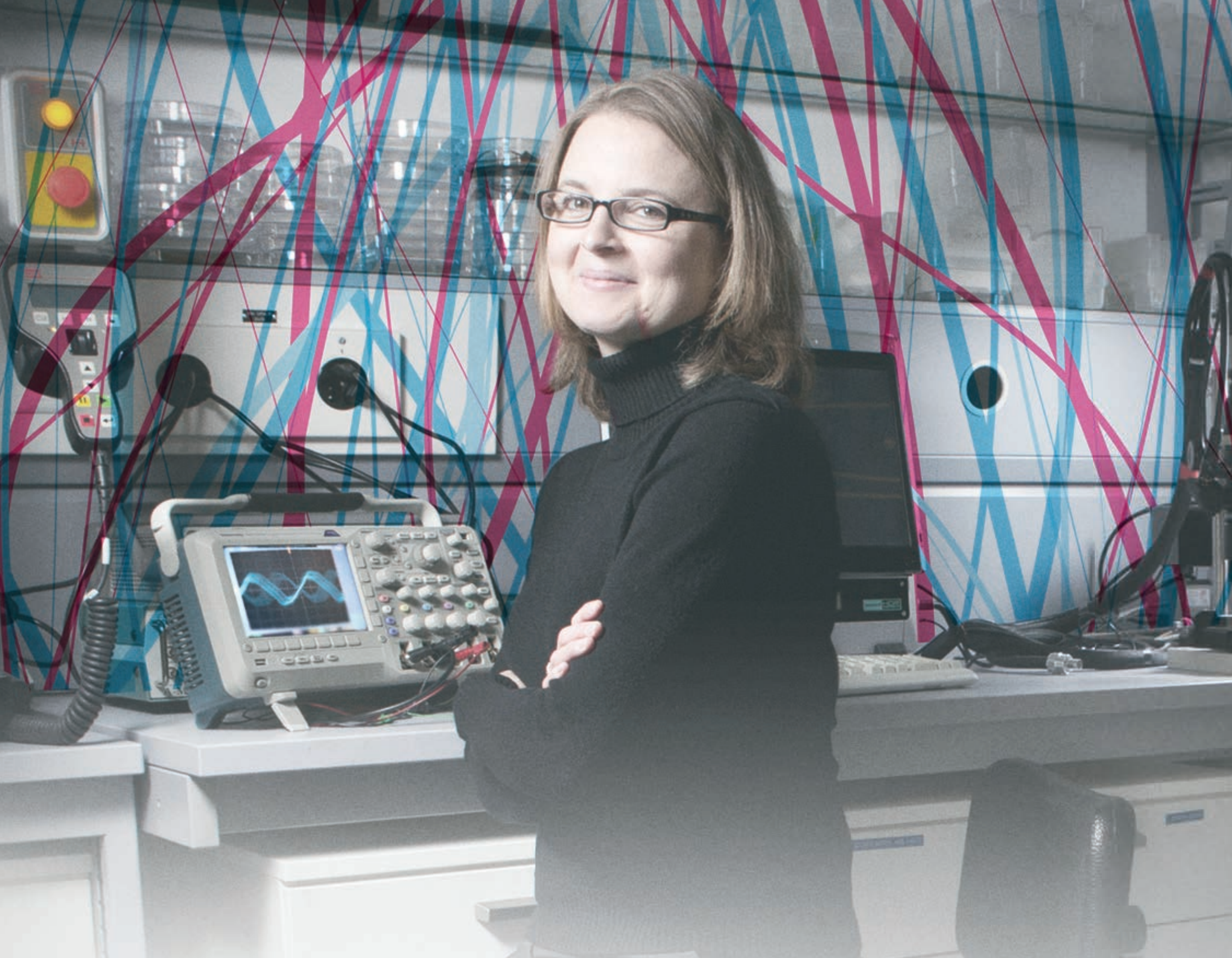

Features

NAUTILUS

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NAUTILUS Next

It's a Wonderful Life

BY KEVIN BERGER

W**E NEED WONDER** in our days."

That's Angus Fletcher, an English professor at Ohio State University, telling *Nautilus* why literature matters. Why science matters. And, more provocatively, how science evolved from literature. Who can argue with him?

Well, you might argue with Fletcher's declaration that literature "is a machine designed to work in concert with another machine, our brain," as he states in our interview, "Why Literature Should Be Taught Like Science."

And that's just Fletcher's opening salvo. In our cover story, "Why Computers Will Never Write Good Novels," he writes that AI boosters who are convinced Hal will one day write beautiful fiction and music, are perpetrating "a hoax, a complete cheat, a total scam, a fiction of the grossest kind."

In short, Fletcher says, computers, based on their design, do not perform causal reasoning. Only the human brain does. Which is why only humans can write literature. Causal reasoning is the engine of the human brain, which generates narratives to guide us through the world. Narratives, in life and literature, despite how fantastical they may be, fuel "plots, characters, and narrators, which give us literary style and voice," Fletcher says. "The best that computers can do is spit out word soups."

Fletcher was born in England's Lake District, stomping ground of Romantic poets Wordsworth and Coleridge. He came to America to attend college, supported by the Marines' ROTC program—"I came up with this fake American accent to avoid being attacked by my drill instructor!"—studied neuroscience, worked in a neurophysiology lab, got a Ph.D. in literature at Yale, worked as a story consultant for films and TV, and is now settled at Ohio State as a professor of "story science."

The wide aperture of Fletcher's intellect, focused with a unique perspective, puts him right at home in *Nautilus*, where science and art come into view through the same lens. In this issue's "Who Said Nobody Read Isaac Newton," Caleb Scharf, our favorite astrobiologist, who was inspired to study science by his parents, professors of art history, dusts off the myth that original works in science, and literature, go unread. Important works most certainly get read, Scharf writes, "or how else would we ever consider them important?"

That people love to read challenging and original works is a clarion message in today's cultural noise about shrinking attention spans. It's a bell we ring with every issue of *Nautilus*.

But wait, before I go, let's get back to wonder. Heidi Hammel, whose insights close this issue, is a planetary astronomer with a long and distinguished career studying Uranus and Neptune. Why has she spent decades studying the "ice giants" of our solar system that neither other astronomers nor the public seems to care about? Because, she says, they "are enigmas."

Why do we need wonder? Because we need science.


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Readers Respond

Comments and letters about stories from print issue 35.

"THE SYNCHRONICITY OF WOLFGANG PAULI AND CARL JUNG"

I read Jung's collected works many years ago. It was striking to observe the clarity of the early works, blending solid observations of psychological regularities with productive speculation. But as I read on, it became obvious that Jung was stuck, unable to find anything beyond more and more speculation, beguiled by the enchanting multiplicities of surface phenomena and myth that he had at his disposal. The later works are unreadable "conspiracy theories," different from other conspiracy theories only in that Jung knew what a conspiracy theory was. I have no doubt that Pauli also knew ... I later read Freud with a sense of relief.

—John Mountfort

"TIME FLOWS TOWARD ORDER"

Are we possibly jumping the gun in our assumption that everything constantly moves from a state of order to disorder? Energy is only one variable—who's to say that complexity does not increase with energy loss and that this complexity, in itself, can one day be a measurable constant. What if disorder eventually, in some inconceivable way, turns back into order, only in a more intangible sense than a physical one. Magma erupts from a volcano in a perfect example of thermodynamic requirement, only to form the foundation for an island that will, one distant day, host life. Energy transforms from one form to another, we just may not have the perceptual savvy to understand the non-physical forms.

—Michael Woronko

Fascinating! For an interesting "pre-cognition" of the expanding universe and its implications, read Edgar Allan Poe's book *Eureka*. He framed his ideas on the solar system, but if you adjust for the universe expanding from a point source, it makes some sense in a poetic/scientific way. His book was rejected by 19th-century science, of course—seen as the delusions of a mad poet—but as you indicate with quotes from Sassoon, poets sometimes have a ground-breaking vision that transcends the accepted version of reality at the time.

—Walter Murch

"TOYS ARE THE FUTURE OF PHILOSOPHY"

This is presented in the abstract, but tweens are right now inventing entire worlds, social systems, cultures, markets, and new modes of collaborative work and interaction in "game" platforms such as Roblox, Minecraft, and Fortnite. They are already modeling the future in play, it might just be hard to see from the perspective of a later generation.

—quietbyday

"WHAT DID THE PAST SMELL LIKE?"

I have always thought about what the past smelled like. I remember the smell inside the old Peking Hotel when I stayed there in 1975. It smelled ancient, a mixture of modern disinfectants, old wood, human smells, smoke and some of the smells of the street coming in. Another olfactory cocktail came from one of those "aooga horns" with the rubber bulb, bought from a Bombay pedicab driver and brought home in 1965. Every time you honked it, the fascinating smell of India came out, rich, complex, spicy, some human effluvium, street smells. I wonder how old some of the molecules are that reach my nasal receptors. Smell is fascinating.

—John Potter

Nautilus *welcomes reader responses. Please email* letters@nautil.us. *All letters are subject to editing.*

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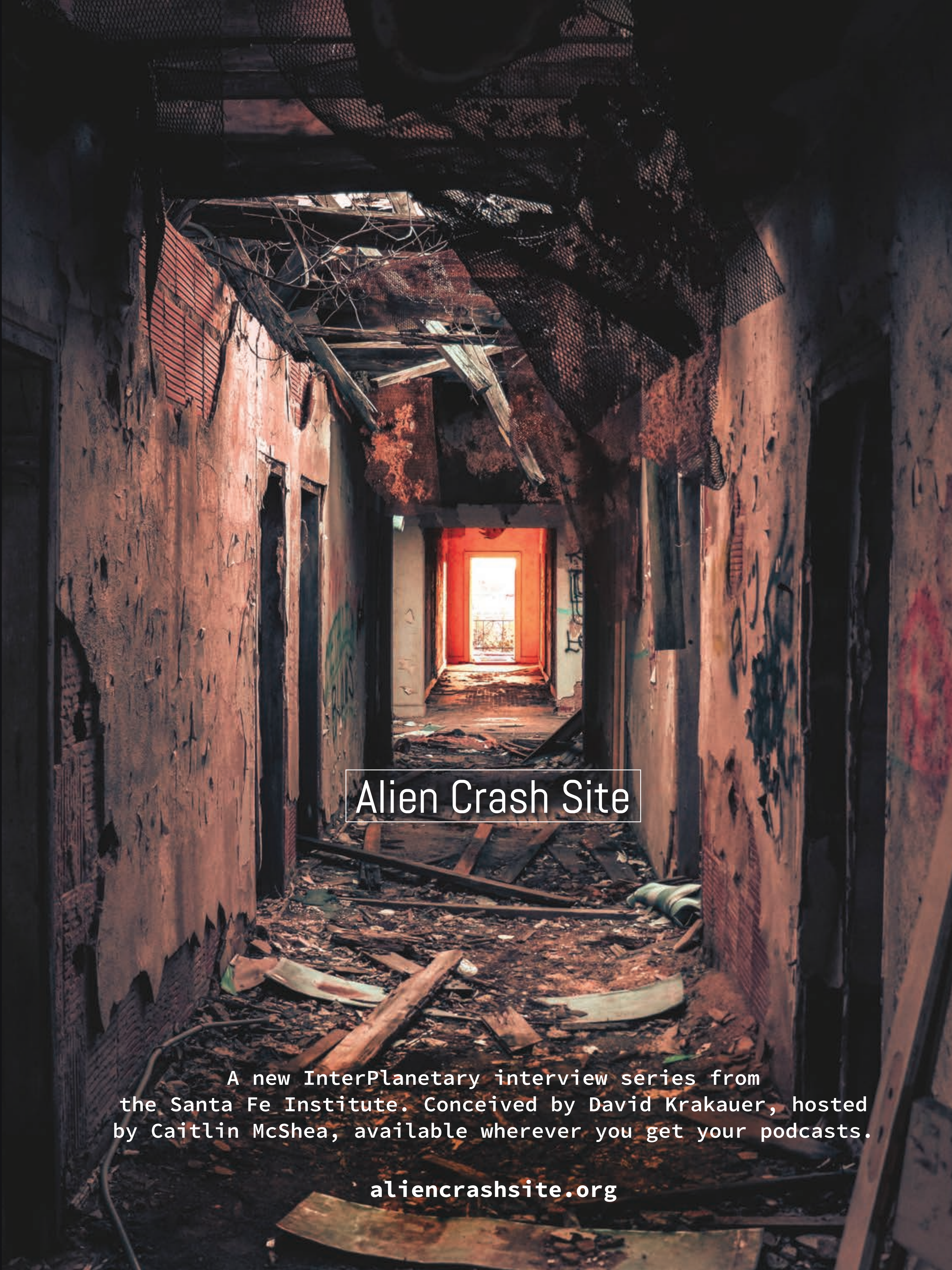
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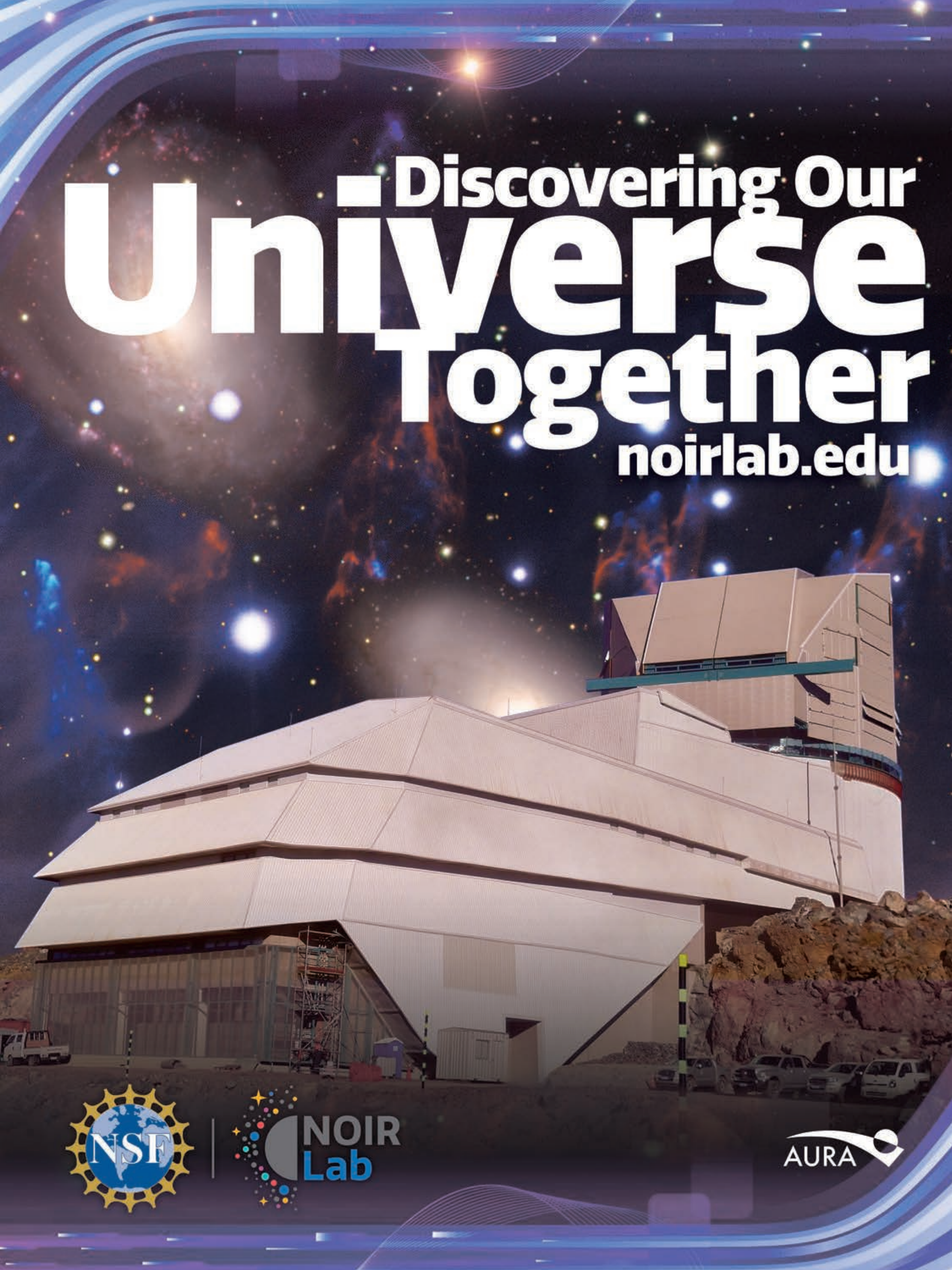
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ASTRONOMY

The Alien-Haunted World

DID YOU KNOW that there are many scientists who devote their working lives to skillfully charting out the most unassuming chunks of our solar system—chunks that none of our species will likely ever see up close? Or who spend day after day wrestling with how to measure and decode the extraordinary orbital dances of unreachable exoplanets, or to detect and interpret the delicate spectra revealing the composition of alien atmospheres tens of trillions of miles away? If not them, then what about those devoted and talented scientists who pursue the exquisite possibility that somewhere there are alien minds sending out structured, information-rich signals, or repurposing their environments in ways that we might just be able to spot across the gaping void of interstellar space?

If you could say yes to any of these questions, well done. You are a well-informed citizen of planet Earth. If, on the other hand, you couldn't respond in the affirmative then perhaps you wouldn't blink at headlines asking why (oh why?!) scientists won't take the task of "looking for aliens" more seriously? Or articles harrumphing about how conservative science is when it comes to "thinking out of the box," especially if the topic is one that's been abused so many times over literally centuries that researchers now have little choice but to apply extreme caution.

I'm referring to the flurry of opinions that have been, in part, triggered by the publication of the book *Extraterrestrial* by theoretical astrophysicist Avi Loeb, in which he attempts to make a case that a recent interstellar object passing through our solar system (the 'Oumuamua object) could have been a piece of technology, conceivably even a tumbling light sail from an alien spacecraft, rather than a piece of frozen rock and gas. Loeb also writes about how science can be overly conservative at times—aiming his complaints in particular on the reticence to elevate the question of alien life to a more prominent place in our hypotheses about what we see in the universe around us.

Most recently (at least as I write this), the trouble is an opinion piece in *The New York Times*: "Aliens Must Be Out There: Why aren't we looking for them?" I think it's fair to say that the tone of the headline, erroneously suggesting that alien life exists because we think it must and that we're not paying attention, reflects much of the thrust of the content. Reaching an apex of sorts when the piece uses Loeb's thoughts on the matter to admonish science, and science-funding agencies, for their "closed-mindedness" and "reflexive skepticism" when it comes to considering exotic (yes, alien) stuff in the mix for explaining new or unexpected cosmic phenomena.

What is so incredibly disappointing for a scientist like myself, and for my colleagues across related disciplines—from astronomy to planetary science to astrobiology—is that there are no other voices represented in this kind of writing. No snippets or quotes from the hundreds of scientists who are the world's experts on matters like 'Oumuamua, or other extraterrestrial objects, from asteroids to comets to interstellar chunks, or the Search for Extraterrestrial Intelligence (SETI), or exoplanets, or indeed the very same quest for so-called technosignatures that is fleetingly mentioned.

In reality there are people who do think about all of these scientific questions, week after week. They dig through mountains of data, and sweat blood over understanding the delicate nature of astronomical measurements and instrumentation. These people are eager and driven, motivated by precisely these same extraterrestrial conundrums: Are we alone? Where do we, or any other life, come from?

Are we alone? Where do we, or any other life, come from?

These scientists have pushed their instruments and skills to the absolute limits in the quest for evidence of extraterrestrial life. Often in the face of intense skepticism. Despite this effort, there has been no evidence to date of extraterrestrial life. But that lack of evidence is not because the scientific enterprise is uniformly conservative, rigid, and close-minded, as implied by Loeb and uncritically echoed by some columnists. It's because no discovery or event has risen to the level where it is inexplicable in any other way.

A proposal that a phenomenon like 'Oumuamua is an alien artifact is certainly going to meet push-back. But that push-back is well founded. It results from the extensive work of scientific experts on precisely this kind of interstellar visitor. Our models of star and planet formation have long hypothesized the existence of leftover pieces of solid material (planetesimals) that could spend eons moving across interstellar space. They have outlined how an interloper like 'Oumuamua would be a stunning discovery. But it would be a stunning discovery reflecting natural processes; reservoirs of these planetesimals that can be ejected and scattered across interstellar space in numbers that may be perfectly consistent with the chances of our solar system being visited by one.

'Oumuamua certainly had puzzling characteristics. It was small for an interstellar comet, it was elongated and, despite being barely caught by our best telescopes and nimblest astronomers as it wended its tumbling way back out of the solar system, it exhibited an ethereal acceleration away from the sun. But even these puzzles are explicable by known processes and are not wildly inconsistent with the properties of other cometary-like objects.

In light of all of this rigorous insight, to shield one's pet hypothesis of an alien object by suggesting that it is not being taken seriously because of a flaw in how we do science is playing a disingenuous game with the facts. As is to suggest that this is actually in aid of raising support for the search for extraterrestrial life.

As in any human intellectual endeavor, there are many voices, many insights. It's too bad that not all insights get the same kind of airtime. If they did, we'd be hearing so much more about the extraordinary ongoing scientific efforts—both institutional and personal—to open up our minds, to explore new worlds, and perhaps discover new life. Are we all carrying out these efforts perfectly? No. Scientific conservatism is present. But so too is a clear memory of the many times where enthusiasm for a provocative idea about alien life has given way to disappointment—from fossils in Martian meteorites to arsenic-laced microbes. Fingers have been burnt before in the quest to find clues to life in the universe.

They weren't burned because of misplaced skepticism though. A wide range of scientists did their own due diligence: scrutinizing a hypothesis, gathering more data, weighing the evidence and building their confidence in a conclusion. Science denialism has cursed many cultures in recent years. Thankfully it looks to be receding somewhat. But being blind to how science works and what it's doing is also a form of denialism. Aliens may be out there. And we are looking for them.

—Caleb Scharf

PSYCHOLOGY

Can You Treat Loneliness with an Imaginary Friend?

LEADIGSZAMMAL / SHUTTERSTOCK

> When you have an imaginary friend, you always have someone to talk to.

DID YOU EVER have an imaginary friend? If you didn't, chances are you know someone who did. Imaginary companions, as scholars call them, are quite common, and aren't strictly associated with childhood. They can last into the upper teen years. One of the most striking things about imaginary companions, which are generally considered harmless, is, of course, their apparent autonomy. To the child, although they know that it is an imaginary being, the friend apparently has a mind of its own—sometimes saying it's too busy to play, for example. This can seem odd, because one of the most common reasons a child creates an imaginary friend is for company.

We can all relate to imaginary characters we can't control—it's the experience we have with the people we meet in our dreams. Dream characters appear autonomous, although they are not. It is more accurate to say that we do not have conscious control over our dream characters. Of course, some part of our mind is controlling those characters; we just experience the illusion that they have minds of their own. Over the last several years, a community of people, interacting mostly in online forums, like Reddit, have discovered a way to create something like imaginary companions as adults. This process is known as tulpamancy, and the people who engage in it call themselves "tulpamancers."

The term "tulpa" seems to originate from Tibetan Buddhism. Samuel Veissière, an anthropologist and cognitive scientist at McGill University, describes tulpas as "imaginary companions who are said to have achieved full sentience after being conjured through 'thoughtform' meditative practice." In other words, this is a benign hallucination. But unlike typical childhood imaginary companions, creating (or "forcing") a tulpa often requires months of hard work. Tulpamancers imagine talking to the tulpa, sometimes for more than an hour a day, and eventually, perhaps after several months, the tulpa will start talking back.

What is interesting to me about this phenomenon, which is only now beginning to be studied scientifically, is the reason that people decide to create a tulpa in the first place: Most often they do it to relieve loneliness. This, too, seems to be connected with imaginary companions. When you have an imaginary friend, or a tulpa, you always have someone to talk to. It can be used as a way to escape unwanted solitude. (Others use them for advice, or to practice social situations that cause anxiety.) "There is likely no causal relation between tulpamancy and the development of psychopathology," a 2017 paper concluded. "Tulpas are an experience of plurality [in consciousness] that seem to coexist with optimal functionality, happiness, and mental health."

The techniques of forcing a tulpa have not been scientifically validated, and now exist only as collected advice and recommendations from practitioners communicating on the Internet. What many aspiring tulpamancers do is imagine their tulpa in a paracosm, an imaginary world, in as vivid detail as possible. They might ascribe things to the tulpa, by saying "You're creative," or "You like mambo music."

But you are not supposed to make the tulpa say anything in your imagination—when the tulpa is "ready," it will speak to you.

If this proves effective, then there is a potential for isolated people to escape some of their loneliness through tulpamancy. Making this happen would only require these practices to be shown to people who have to spend a lot of time alone.

One of the main concerns of space travel is the mental health and loneliness of astronauts. An astronaut's communication with Earth is slowed down considerably by the limitations of the speed of light. Mars is between about four and 24 light-minutes away from Earth, depending on where these planets are in their orbits. Conversations where each communication takes four minutes to arrive are stilted, to say the least. So it is exciting to think that some solutions to the challenge of prolonged solitude might be achievable just through the use of our own minds.

—Jim Davies

PHILOSOPHY

Should Marine Species Own the High Seas?

LATER THIS YEAR, the United Nations will finish hosting the final negotiations on a new conservation treaty for the high seas, as waters that lie outside national jurisdiction are known. These cover more than half of Earth's surface and contain much of the planet's biodiversity. The moment marks a tremendous opportunity in humanity's losing battle against biodiversity loss.

Thus far, conversations about how best to protect the high seas have missed a crucial element, one that could well be the single boldest, most important conservation move that humankind could make: recognizing the property interests of the marine species now living there.

Every whale and shark and sea turtle, every tuna and toothfish, every octopus and even every salp and sea urchin and anemone, has a right to own their part of the ocean.

What does it mean to say that animals have a right to own property? To many people this might seem like a radical idea. Those who follow animal law might say that it's too big an ask. After all, it's generally understood that in the United States and most of the world's nations, animals have very limited legal rights. When activists have fought for legal personhood for animals, they have usually lost.

It's not so unprecedented, though. Many existing laws afford certain non-human animals legal interests to the environments in which they live. In the U.S., for example, a golden eagle's claim to the tree in which

NOAA / NMFS / PACIFIC ISLANDS FISHERIES SCIENCE CENTER BLOG

she nests outweighs the right of the tree's human landowners to cut it down. Most public lands are partially managed for animal interests. In the past decade, most states have enacted laws allowing pets to own property bequeathed to them in trust. Some tribal nations in the U.S. have afforded legal personhood to natural entities, such as wild rice in Chippewa ceded territories, which would allow humans to file lawsuits in tribal courts on behalf of rice. Outside the U.S., New Zealand's Whanganui River was granted legal personhood in 2017, and Ecuador's constitution explicitly recognizes the rights of nature to persist and regenerate. Once unthinkable assertions of rights for nature's beings are becoming commonplace.

These developments lay the foundations for explicitly recognizing wildlife as property owners. In contrast to how legal scholars historically viewed property—with ownership as an all-or-nothing affair—new models envision property rights as overlapping, a pluralistic conception of ownership in which humans

> Every whale and shark and sea turtle has a right to own their part of the ocean.

and nonhumans alike can both have legally actionable interests in the same physical space. In this way, modern property law is beginning to embrace what many Indigenous cultures never forgot: Plants and nonhuman animals are our co-participants in life on Earth. This suggests that marine species could be understood as owners of the oceanic commons they occupy or, at least co-owners.

What would this mean in practice? A formal recognition of rights would advance marine species' interests in the high seas—and not merely through the human-centered goal of sustainable management of fisheries, but by elevating the larger biodiversity goals that are at the center of the high seas treaty negotiations now taking place.

Right now, however, negotiators at the U.N. are actually moving in the opposite direction. They're considering dividing the high seas between nations and regions. Nonhuman rights are not on the table.

To be sure, this is part of conversations that also include proposals for marine protected areas and restrictions on high seas fishing, both of which would do much to advance the interests of nonhuman ocean users. But divvying up the ocean without formally acknowledging the ownership interests of the creatures now living there replicates the fatal flaw that colonial governments made when they demarcated land boundaries. Rather than being required to consider the rights of wildlife in future actions, countries and regional management organizations will be able to diminish them even further.

That's especially likely if regional fisheries management organizations acquire more power, which seems likely. They have a poor track record of biodiversity preservation—and, if given the chance, nations engaged in economic competition over the high seas' resources will engage in a race to the bottom. Devastating biodiversity loss will almost certainly occur, hastening the sixth extinction.

To avoid further expropriating Earth from other species, the new treaty should permanently title the high seas to its animal occupants. This would radically shift humankind's trajectory—but, vitally, it would not eliminate human uses of the high seas. Humans could still catch fish and ship goods. It would simply require animal interests in having thriving ecosystems to be represented far more robustly than they have been.

The high seas represents a rare opportunity to preserve animal interests on a global scale; the U.N. has the power to shift the course of life on Earth for the better. We must not waste it.

—*Karen Bradshaw*

ASTRONOMY

We're the Cosmic 1 Percent

IS EARTH UNIQUE? Once a grand philosophical question, it has become, with the discovery of thousands of planets around other stars over the past two decades, a scientific one.

One way to address it is to imagine aliens, using present-day Earth technology, searching our solar system for exoplanets. Which of our eight planets would they find? The answer is Jupiter, and only Jupiter. Our exoplanet-searching techniques look for the effect of planets on their host star, either through a cyclical gravitational tug, or by periodically blinking out some of the star's light. Jupiter would only be detectable (for now) through a decades-long radial velocity survey of the sun. We could measure Jupiter's approximate mass and orbit. The question then becomes: How common, among known exoplanets, are systems similar to the sun-Jupiter system?

About 1 percent. Gas giants with masses similar to Jupiter's are found around approximately 1 in 10 stars like the sun; however, only about 1 in 10 of *those* planets has a "Jupiter-like" orbit, meaning an orbit that is significantly wider than Earth's and close to circular. Of course, we still have no data on Earths or Venuses or Saturns or Neptunes around other stars like the sun. But it's a start.

VADIM SADOVSKI / SHUTTERSTOCK

When putting something in context, 1 percent is a tricky number.

A second way to gauge our solar system's uniqueness comes from Nanna Bach-Møller and Uffe Jørgensen. They base their argument on a relation between the number of planets in a given system and the shapes of planets' orbits. The key piece of their analysis, published in the *Monthly Notices of the Royal Astronomical Society*, is "orbital eccentricity." Kepler's laws of orbital motion tell us that planets orbit their host stars following ellipses. The eccentricity of an ellipse is a measure of how stretched out it is. An ellipse with zero eccentricity is a circle; as the eccentricity approaches one, the ellipse becomes infinitely stretched out.

While a planet on a circular orbit moves at a constant speed around the star, planets on eccentric orbits move faster when they are closer to the star. Scientists can detect this change in orbital speed over the orbit for exoplanets using different techniques.

Bach-Møller and Jørgensen started by gathering the full sample of exoplanets for which researchers have already measured or estimated orbital eccentricities, and then calculated an "average eccentricity" for all of the planets in each system. They found that systems with more planets tend to have lower eccentricities.

This is not a big surprise. Scientists can search for exoplanets only within a limited range of orbital distances. Imagine a washing machine-sized cardboard box. How many smaller boxes can you fit inside that big box if you have to put each box inside another box (like Russian dolls)? It depends on their shapes. If your boxes are all nice and square, then you might be able to fit a dozen or more inside each other. But if even one box is a stretched-out guitar-shaped box, then fewer boxes will be able to fit inside the big box.

It's the same idea for orbits. Planets on circular orbits can be packed much closer together than planets on stretched-out, eccentric orbits. And the more eccentric the orbits, the fewer can fit in the range in orbital distance that we can search for exoplanets.

The researchers put numbers on orbits-inside-orbits. They found that the number of planets in a given system, versus the average eccentricity, follows a smooth relation—with just one exception. Systems with a single planet are a little bit off. These systems may have started off with many planets on near-circular orbits that, through cumulative gravitational kicks, changed their shapes until they crossed. This would have led to close gravitational scattering events that launched some planets into interstellar space!

With eight planets on relatively circular orbits, our solar system fits the trend. With this trend, the researchers use the occurrence-rate of exoplanets with different eccentricities to estimate how many systems have as many planets as ours. Their answer: About 1 percent, the same as we estimated using the sun-Jupiter system.

When putting something in context, 1 percent is a tricky number. It's rare enough to fall outside of the norm. Indeed, about half of all stars seem to have "super-Earth" planets on orbits closer to their stars than Mercury is to the sun, but we don't. One percent is also frequent enough not to be completely unexpected, and we have found some signs that our solar system isn't a complete weirdo, including the discovery of a handful of reasonable analogs to our own Jupiter.

What does this tell us about where our system came from? The past decade has seen considerable progress in understanding how our solar system formed, yet key questions remain. What were the branching points in our planetary evolution that turned us into a 1-percent system rather than a more common one dominated by super-Earths? What made our Jupiter different from most of the exo-Jupiters we've found? And how does the growth and survival of rocky planets like Earth fit into this picture? The answer may lie in the shapes of our orbits.

—Sean Raymond

Strangers and Foreigners

ONE OF THE MOST astonishing things you'll ever do is walk into a busy cafe without a thought. A chimpanzee, faced by other chimpanzees it doesn't know, would likely run away in terror. For sure, the chimpanzees I photographed in this grooming huddle on my trek through Gombe, Tanzania, had to know each other well. Why the difference from humans?

An essential feature of any society is the capacity of its members to distinguish one another from outsiders. As I came to realize while preparing to write my most recent book, *The Human Swarm: How Our Societies Arise, Thrive, and Fall*, in most vertebrates, including the chimpanzee, society members must remember each other as individuals to stay clearly separated from foreign groups. Such species have societies of a few dozen, maximum, a population ceiling likely determined in part by the challenges each animal experiences in keeping track of everyone who belongs.

These societies differ from those of insects, in which membership can be anonymous: Ants are "marked" by a scent that serves as a kind of national flag, permitting colonies of this swarming *Crematogaster* in Ghana to grow enormous. In this, ants are simplified versions of ourselves—humans are demarcated by a plethora of traits like rituals, dress, hairstyles, gestures, and language that enable people to perceive strangers as *one of us*.

—Mark W. Moffett

Photos by the author

Why Computers Will Never Write Good Novels

The power of narrative flows only from the human brain

BY ANGUS FLETCHER

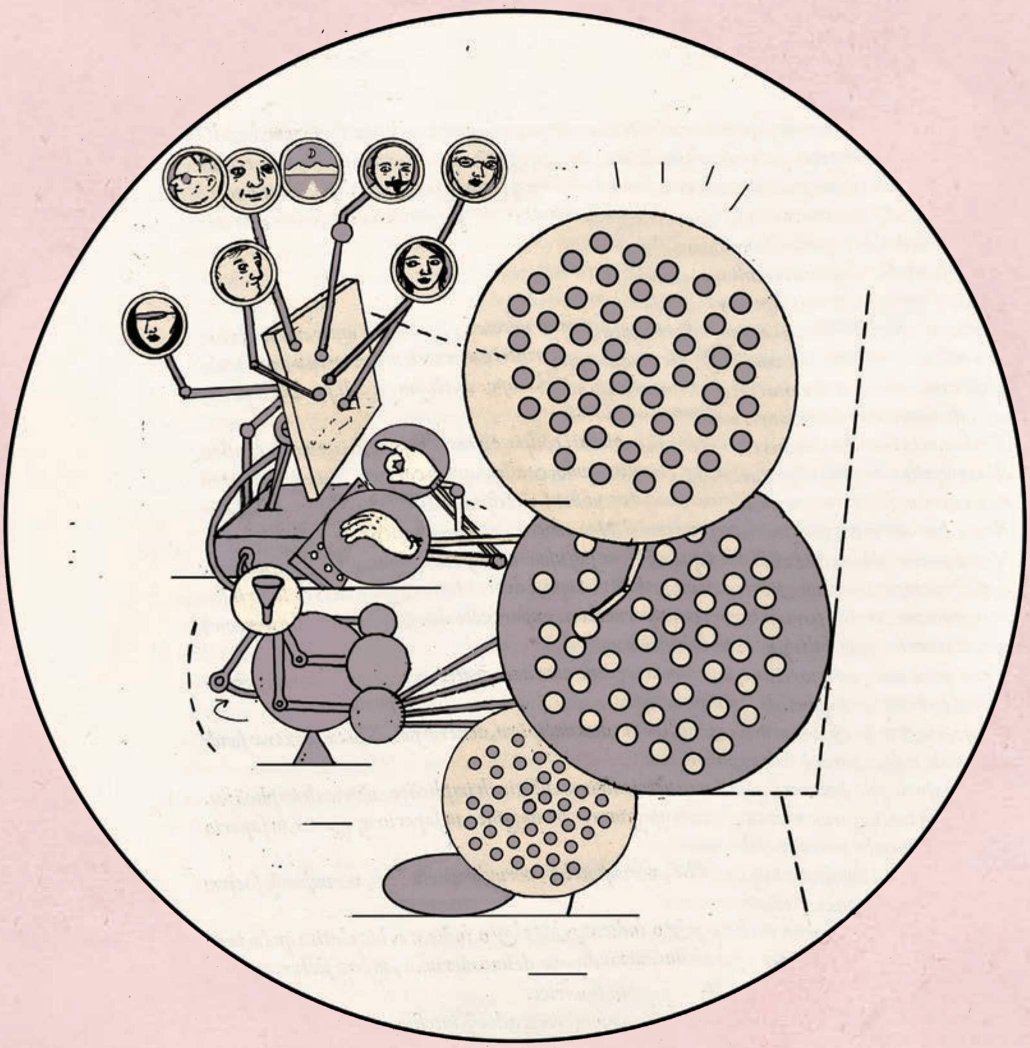


ILLUSTRATION BY JONATHON ROSEN

YOU'VE BEEN HOAXED.

The hoax seems harmless enough. A few thousand AI researchers have claimed that computers can read and write literature. They've alleged that algorithms can unearth the secret formulas of fiction and film. That Bayesian software can map the plots of memoirs and comic books. That digital brains can pen primitive lyrics[1] and short stories—wooden and weird, to be sure, yet evidence that computers are capable of more.

But the hoax is not harmless. If it were possible to build a digital novelist or poetry analyst, then computers would be far more powerful than they are now. They would in fact be the most powerful beings in the history of Earth. Their power would be the power of literature, which although it seems now, in today's glittering Silicon Age, to be a rather unimpressive old thing, springs from the same neural root that enables human brains to create, to imagine, to dream up tomorrows. It was the literary fictions of H.G. Wells that sparked Robert Goddard to devise the liquid-fueled rocket, launching the space epoch; and it was poets and playwrights—Homer in *The Iliad*, Karel Čapek in *Rossumovi Univerzální Roboti*—who first hatched the notion of a self-propelled metal robot, ushering in the wonder-horror of our modern world of automata.

If computers could do literature, they could invent like Wells and Homer, taking over from sci-fi authors to engineer the next utopia-dystopia. And right now, you probably suspect that computers are on the verge of doing just so: *Not too far in the future, maybe in my lifetime even, we'll have a computer that creates, that imagines, that dreams.* You think that because you've been duped by the hoax. The hoax, after all, is everywhere: college classrooms, public libraries, quiz games, IBM, Stanford, Oxford, Hollywood. It's become such a pop-culture truism that *Wired* enlisted an algorithm, SciFiQ, to craft "the perfect piece of science fiction."[2]

Yet despite all this gaudy credentialing, the hoax is a complete cheat, a total scam, a fiction of the grossest kind. Computers can't grasp the most lucid haiku. Nor can they pen the clumsiest fairytale. Computers cannot read or write literature at all. And they *never, never* will.

I can prove it to you.

At the bottom of literature's strange and branching multiplicity is an engine of causal reasoning.

COMPUTERS POSSESS BRAINS of unquestionable brilliance, a brilliance that dates to an early spring day in 1937 when a 21-year-old master's student found himself puzzling over an ungainly contraption that looked like three foosball tables pressed side-to-side in an electrical lab at the Massachusetts Institute of Technology.

The student was Claude Shannon. He'd earned his undergraduate diploma a year earlier from the University of Michigan, where he'd become fascinated with a system of logic devised during the 1850s by George Boole, a self-taught Irish mathematician who'd managed to vault himself, without a university degree, into an algebra professorship at Queen's College, Cork. And eight decades after Boole pulled off that improbable leap, Shannon pulled off another. The ungainly foosball contraption that sprawled before him was a "differential analyzer," a wheel-and-disc analogue computer that solved physics equations with the help of electronic switchboards. Those switchboards were a convoluted mess of ad hoc cables and transistors that seemed to defy reason when suddenly Shannon had a world-changing epiphany: *Those switchboards and Boole's logic spoke the same language.* Boole's logic could simplify the switchboards, condensing them into circuits of elegant precision. And the switchboards could then solve all of Boole's logic puzzles, ushering in history's first automated logician.

With this jump of insight, the architecture of the modern computer was born. And as the ensuing years have proved, the architecture is one of enormous potency. It can search a trillion webpages, dominate strategy games, and pick lone faces out of a crowd—and every day, it stretches still further, automating more of our vehicles, dating lives, and daily meals. Yet as dazzling as all these tomorrow-works are, the best way to understand the true power of computer thought isn't to peer forward into the future fast-approaching. It's to look backward in time, returning our gaze to the original source of Shannon's epiphany. Just as that epiphany rested on the earlier insights of Boole, so too did Boole's insights[3] rest on a work more ancient still: a scroll authored by the Athenian polymath Aristotle in the fourth century B.C.

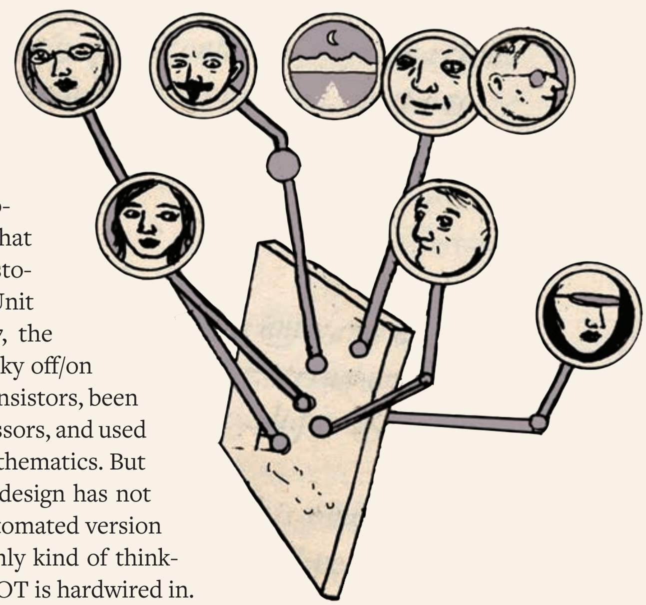
The scroll's title is arcane: *Prior Analytics*. But its purpose is simple: to lay down a method for finding the truth. That method is the syllogism. The syllogism distills all logic down to three basic functions: AND, OR, NOT. And with those functions, the syllogism unerringly distinguishes what's TRUE from what's FALSE.

So powerful is Aristotle's syllogism that it became the uncontested foundation of formal logic throughout Byzantine antiquity, the Arabic middle ages, and the European Enlightenment. When Boole laid the mathematical groundwork for modern computing, he could begin by observing:

> The subject of Logic stands almost exclusively associated with the great name of Aristotle. As it was presented to ancient Greece … it has continued to the present day.

This great triumph prompted Boole to declare that Aristotle had identified "the fundamental laws of those operations of the mind by which reasoning is performed." Inspired by the Greek's achievement, Boole decided to carry it one step further. He would translate Aristotle's syllogisms into "the symbolical language of a Calculus," creating a mathematics that thought like the world's most rational human.

In 1854, Boole published his mathematics as *The Laws of Thought*. *The Laws* converted Aristotle's FALSE and TRUE into two digits—zero and 1—that could be crunched by AND-OR-NOT algebraic equations. And 83 years later, those equations were given life by Claude Shannon. Shannon discerned that the differential analyzer's electrical off/on switches could be used to animate Boole's 0/1 bits. And Shannon also experienced a second, even more remarkable, realization: The same switches could automate Boole's mathematical syllogisms. One arrangement of off/on switches could calculate AND, and a second could calculate OR, and a third could calculate NOT, Frankensteining an electron-powered thinker into existence.

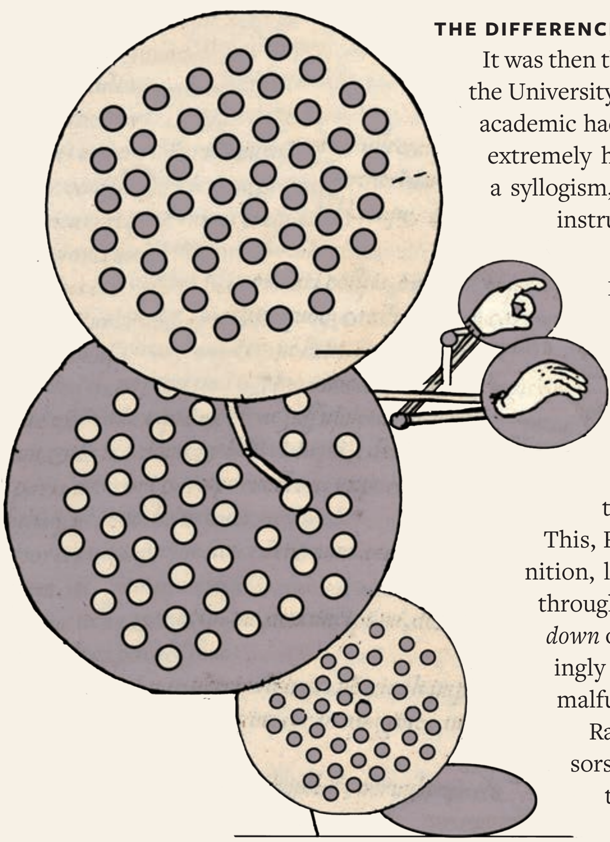


Shannon's mad-scientist achievement established the blueprint for the computer brain. That brain, in homage to Boole's arithmetic and Aristotle's logic, is known now as the Arithmetic Logic Unit or ALU. Since Shannon's breakthrough in 1937, the ALU has undergone a legion of upgrades: Its clunky off/on switch-arrangements have shrunk to miniscule transistors, been renamed logic gates, multiplied into parallel processors, and used to perform increasingly sophisticated styles of mathematics. But through all these improvements, the ALU's core design has not changed. It remains as Shannon drew it up, an automated version of the syllogism, so syllogistic reasoning is the only kind of thinking that computers can do. Aristotle's AND-OR-NOT is hardwired in.

This hardwiring has hardly seemed a limitation. In the late 19th century, the American philosopher C.S. Peirce deduced that AND-OR-NOT could be used to compute the essential truth of anything: "mathematics, ethics, metaphysics, psychology, phonetics, optics, chemistry, comparative anatomy, astronomy, gravitation, thermodynamics, economics, the history of science, whist, men and women, wine, meteorology." And in our own time, Peirce's deduction has been bolstered by the advent of machine learning. Machine learning marshals the ALU's logic gates to perform the most astonishing feats of artificial intelligence, enabling Google's DeepMind, IBM's Watson, Apple's Siri, Baidu's PaddlePaddle, and Amazon's Web Services to reckon a person's odds of getting sick, alert companies to possible frauds, winnow out spam, become a whiz at multiplayer video games, and estimate the likelihood that you'd like to purchase something you don't even know exists.

Although these remarkable displays of computer cleverness all originate in the Aristotelian syllogisms that Boole equated with the human mind, it turns out that the logic of their thought is different from the logic that you and I typically use to think.

Very, very different indeed.



THE DIFFERENCE WAS DETECTED back in the 16th century.

It was then that Peter Ramus, a half-blind, 20-something professor at the University of Paris, pointed out an awkward fact that no reputable academic had previously dared to admit: Aristotle's syllogisms were extremely hard to understand.[4] When students first encountered a syllogism, they were inevitably confused by its truth-generating instructions:

> If no β is α, then no α is β, for if some α (let us say δ) were β, then β would be α, for δ is β. But if all β is α, then some α is β, for if no α were β, then no β could be α …

And even after students battled through their initial perplexity, valiantly wrapping their minds around Aristotle's abstruse mathematical procedures, it still took years to acquire anything like proficiency in Logic.

This, Ramus thundered, was oxymoronic. Logic was, by definition, logical. So, it should be immediately obvious, flashing through our mind like a beam of clearest light. It shouldn't *slow down* our thoughts, requiring us to labor, groan, and painstakingly calculate. All that head-strain was proof that Logic was malfunctioning—and needed a fix.

Ramus' denunciation of Aristotle stunned his fellow professors. And Ramus then startled them further. He announced that the way to make Logic more intuitive was to turn away from the syllogism. And to turn toward literature.

Literature exchanged Aristotle's AND-OR-NOT for a different logic: the logic of nature. That logic explained why rocks dropped, why heavens rotated, why flowers bloomed, why hearts kindled with courage. And by doing so, it equipped us with a handbook of physical power. Teaching us how to master the things of our world, it upgraded our brains into scientists.

Literature's facility at this practical logic was why, Ramus declared, God Himself had used myths and parables to convey the workings of the cosmos. And it was why literature remained the fastest way to penetrate the nuts and bolts of life's operation. What better way to grasp the intricacies of reason than by reading Plato's Socratic dialogues? What better way to understand the follies of emotion than by reading Aesop's fable of the sour grapes? What better way to fathom war's empire than by reading Virgil's *Aeneid*? What better way to pierce that mystery of mysteries—love—than by reading the lyrics of Joachim du Bellay?

Inspired by literature's achievement, Ramus tore up Logic's traditional textbooks. And to communicate life's logic in all its rich variety, he crafted a new textbook filled with sonnets and stories. These literary creations explained the previously incomprehensible reasons of lovers, philosophers, fools, and gods—and did so with such graceful intelligence that learning felt easy. Where the syllogisms of Aristotle had ached our brains, literature knew just how to talk so that we'd comprehend, quickening our thoughts to keep pace with its own.

Ramus' new textbook premiered in the 1540s, and it struck thousands of students as a revelation. For the first time in their lives, those students opened a Logic primer—and felt the flow of their innate method of reasoning, only executed faster and more precisely. Carried by a wave of student enthusiasm, Ramus' textbooks became bestsellers across Western Europe, inspiring educators from Berlin to London to celebrate literature's intuitive logic: "Read Homer's *Iliad* and that most worthy ornament of our English tongue, the *Arcadia* of Sir Philip Sidney—and see the true effects of Natural Logic, far different from the Logic dreamed up by some curious heads in obscure schools."[5]

Four-hundred years before Shannon, here was his dream of a logic-enhancer—and yet the blueprint was radically different. Where Shannon tried to engineer a go-faster human mind with electronics, Ramus did it with literature.

The hoax is everywhere: college classrooms, IBM, Stanford, Oxford, Hollywood.

So who was right? Do we make ourselves more logical by using computers? Or by reading poetry? Does our next-gen brain lie in the CPU's Arithmetic Logic Unit? Or in the fables of our bookshelf?

To our 21st-century eyes, the answer seems obvious: The AND-OR-NOT logic of Aristotle, Boole, and Shannon is the undisputed champion. Computers—and their syllogisms—rule our schools, our offices, our cars, our homes, our everything. Meanwhile, nobody today reads Ramus' textbook. Nor does anyone see literature as the logic of tomorrow. In fact, quite the opposite: Enrollments in literature classes at universities worldwide are contracting dramatically. Clearly, there is no "natural logic" inside our heads that's accelerated by the writings of Homer and Maya Angelou.

Except, there is. In a recent plot twist, neuroscience has shown that Ramus got it right.

OUR NEURONS can fire—or not.

This basic on/off function, observed pioneering computer scientist John von Neumann, makes our neurons appear similar—even identical—to computer transistors. Yet transistors and neurons are different in two respects. The first difference was once thought to be very important, but is now viewed as basically irrelevant. The second has been almost entirely overlooked, but is very important indeed.

Do we make ourselves more logical by using computers? Or by reading poetry?

The first—basically irrelevant—difference is that transistors speak in digital while neurons speak in analogue. Transistors, that is, talk the TRUE/FALSE absolutes of 1 and 0, while neurons can be dialed up to "a tad more than 0" or "exactly ¾." In computing's early days, this difference seemed to doom artificial intelligences to cogitate in black-and-white while humans mused in endless shades of gray. But over the past 50 years, the development of Bayesian statistics, fuzzy sets, and other mathematical techniques have allowed computers to mimic the human mental palette, effectively nullifying this first difference between their brains and ours.

The second—and significant—difference is that neurons can control the *direction* of our ideas. This control is made possible by the fact that our neurons, as modern neuroscientists and electrophysiologists have demonstrated, fire in a single direction: from dendrite to synapse. So when a synapse of neuron A opens a connection to a dendrite of neuron Z, the ending of A becomes the beginning of Z, producing the one-way circuit A → Z.

This one-way circuit is our brain thinking: A *causes* Z. Or to put it technically, it's our brain performing causal reasoning.

Causal reasoning is the neural root of tomorrow-dreaming teased at this article's beginning. It's our brain's ability to think: *this-leads-to-that*. It can be based on some data or no data—or even go against all data. And it's such an automatic outcome of our neuronal anatomy that from the moment we're born, we instinctively think in its story sequences, cataloguing the world into *mother-leads-to-pleasure* and *cloud-leads-to-rain* and *violence-leads-to-pain*. Allowing us, as we grow, to invent afternoon plans, personal biographies, scientific hypotheses, business proposals, military tactics, technological blueprints, assembly lines, political campaigns, and other original chains of cause-and-effect.

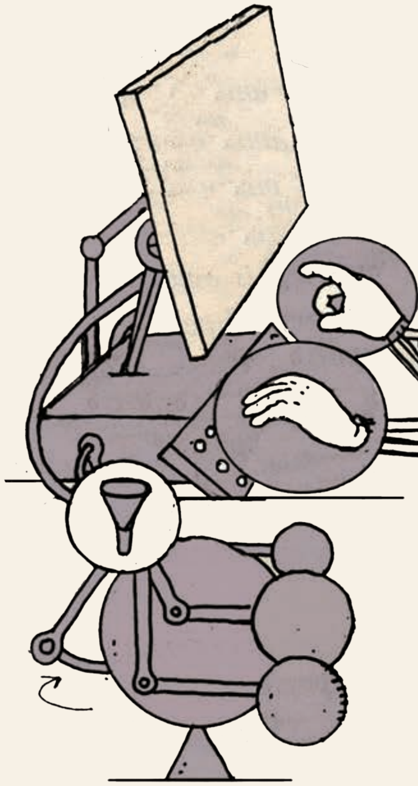
But as natural as causal reasoning feels to us, computers can't do it. That's because the syllogistic thought of the computer ALU is composed of mathematical equations, which (as the term "equation" implies) take the form of *A equals Z*. And unlike the connections made by our neurons, *A equals Z* is not a one-way route. It can be reversed without changing its meaning: *A equals Z* means exactly the same as *Z equals A*, just as 2 + 2 = 4 means precisely the same as 4 = 2 + 2.

This feature of *A equals Z* means that computers can't think in *A causes Z*. The closest they can get is "if-then" statements such as: "*If* Bob bought this toothpaste, *then* he will buy that toothbrush." This can look like causation but it's only correlation. Bob buying toothpaste doesn't *cause* him to buy a toothbrush. What causes Bob to buy a toothbrush is a third factor: wanting clean teeth.

Computers, for all their intelligence, cannot grasp this. Judea Pearl, the computer scientist whose groundbreaking work in AI led to the development of Bayesian networks, has chronicled that the if-then brains of computers see no meaningful difference between Bob buying a toothbrush because he bought toothpaste and Bob buying a toothbrush because he wants clean teeth. In the language of the ALU's transistors, the two equate to the very same thing.

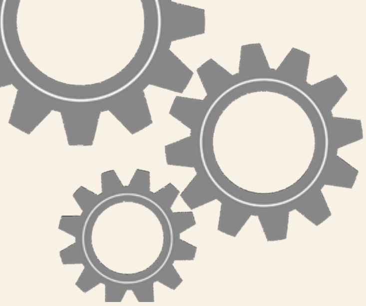
This inability to perform causal reasoning means that computers cannot do all sorts of stuff that our human brain can. They cannot escape the mathematical present-tense of *2 + 2 is 4* to cogitate in *was* or *will be*. They cannot think historically or hatch future schemes to do anything, including take over the world.

And they cannot write literature.



LITERATURE IS A WONDERWORK of imaginative weird and dynamic variety. But at the bottom of its strange and branching multiplicity is an engine of causal reasoning. The engine we call narrative.

Narrative cranks out chains of *this-leads-to-that*. Those chains form literature's story plots and character motives, bringing into being the events of the *Iliad* and the soliloquies of *Hamlet*. And those chains also comprise the literary device known as the narrator, which (as narrative theorists from the Chicago School[6] onward have shown) generate novelistic *style* and poetic *voice*, creating the postmodern flair of "Rashōmon" and the fierce lyricism of *I Know Why the Caged Bird Sings*.



> The best that computers can do is spit out word soups. They leave our neurons unmoved.

No matter how nonlogical, irrational, or even madly surreal literature may feel, it hums with narrative logics of cause-and-effect. When Gabriel García Márquez begins *One Hundred Years of Solitude* with a mind-bending scene of discovering ice, he's using *story* to explore the *causes* of Colombia's circular history. When William S. Burroughs dishes out delirious syntax in his opioid-memoir *Naked Lunch*—"his face torn like a broken film of lust and hungers of larval organs stirring"—he's using *style* to explore the *effects* of processing reality through the pistons of a junk-addled mind.

Narrative's technologies of plot, character, style, and voice are why, as Ramus discerned all those centuries ago, literature can plug into our neurons to accelerate our causal reasonings, empowering *Angels in America* to propel us into empathy, *The Left Hand of Darkness* to speed us into imagining alternate worlds, and a single scrap of Nas, "I never sleep, because sleep is the cousin of death," to catapult us into grasping the anxious mindset of the street.

None of this narrative think-work can be done by computers, because their AND-OR-NOT logic cannot run sequences of cause-and-effect. And that inability is why no computer will ever pen a short story, no matter how many pages of Annie Proulx or O. Henry are fed into its data banks. Nor will a computer ever author an Emmy-winning television series, no matter how many *Fleabag* scripts its silicon circuits digest.

The best that computers can do is spit out word soups. Those word soups are syllogistically equivalent to literature. But they're narratively different. As our brains can instantly discern, the verbal emissions of computers have no literary style or poetic voice. They lack coherent plots or psychologically comprehensible characters. They leave our neurons unmoved.

This isn't to say that AI is dumb; AI's rigorous circuitry and prodigious data capacity make it far smarter than us at Aristotelian logic. Nor is it to say that we humans possess some metaphysical creative essence—like freewill—that computers lack. Our brains are also machines, just ones with a different base mechanism.

But it is to say that there's a dimension—the narrative dimension of time—that exists beyond the ALU's mathematical present. And our brains, because of the directional arrow of neuronal transmission, can think in that dimension.

Our thoughts in time aren't necessarily right, good, or true—in fact, strictly speaking, since time lies outside the syllogism's timeless purview, none of our *this-leads-to-that* musings qualify as candidates for rightness, goodness, or truth. They exist forever in the realm of the speculative, the counterfactual, and the fictional. But even so, their temporality allows our mortal brain to do things that the superpowered NOR/NAND gates of computers never will. Things like plan, experiment, and dream.

Things like write the world's worst novels—and the greatest ones, too.

ANGUS FLETCHER is Professor of Story Science at Ohio State's Project Narrative and the author of *Wonderworks: The 25 Most Powerful Inventions in the History of Literature*. His peer-reviewed proof that computers cannot read literature was published in January 2021 in the literary journal, *Narrative*.

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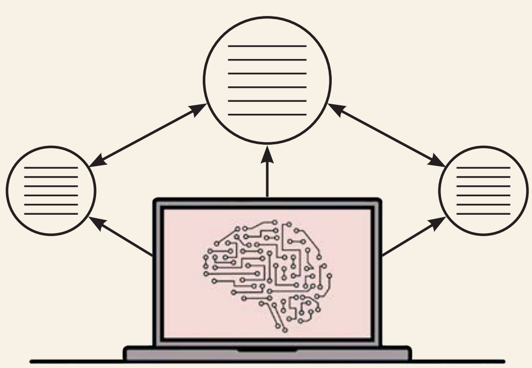


Literature Should Be Taught Like Science

This renegade professor says literature is a machine that accelerates the human brain

BY KEVIN BERGER

IN THE PAST QUARTER CENTURY, enrollment in college English departments has sunk like the Pequod in *Moby Dick*. Meanwhile enrollment in science programs has skyrocketed. It's understandable. Elon Musk, not Herman Melville, is the role model of the digital economy. But it doesn't have to be that way, says Angus Fletcher, 44, an English professor at Ohio State University. Fletcher is part of "group of renegades," he says, who are on a mission to plug literature back into the electric heart of contemporary life and culture. Fletcher has a plan—"apply science and engineering to literature"—and a syllabus, *Wonderworks: The 25 Most Powerful Inventions in the History of Literature*, his new book.

Before the England-born Fletcher got his Ph.D. in literature at Yale, he earned an undergraduate degree in neuroscience, followed by a four-year stint in a neurophysiology lab at the University of Michigan. He switched careers when he realized the biology of the brain wouldn't take him far enough toward understanding our need for stories. "What's special about the human brain is its power of storytelling," Fletcher says. "Its power of narrative. Its power to invent futures and tell our past. So, I thought, 'I'll go to an English department and learn about narrative.' " Fletcher sees the human brain as mechanical, but insists it doesn't operate like a computer. He spelled out his view for *Nautilus* readers in our cover story, "Why Computers Will Never Write Good Novels."

Wonderworks consists of 25 chapters that delve into works from the *Iliad* to *Emma*, *In Search of Lost Time* to *My Brilliant Friend*, each representative of a particular "invention" to lighten sorrow or grief or create empathy or joy. "Each of these inventions had a unique purpose, engineered with its own intricate circuitry to click into our psyche in a different way," Fletcher writes. *Wonderworks* is captivating, as is Fletcher, who speaks with infectious enthusiasm and clarity. I began our conversation on Zoom with a question about the difference between the human brain and a computer, the subject of his *Nautilus* article, and then turned to his provocative view that to save the humanities, literature must be taught as a science.

ANDREY_KUZMIN / SHUTTERSTOCK

Is a big part of the difference between human brains and computers the fact that computers lack consciousness?

No. I'm making a completely mechanical argument for novels, literature, and narrative. Consciousness is like the existence of the 913th dimension. It may exist. It's not up to me to say that it doesn't exist. But I can tell you right now, no human is ever going to establish a definitive proof one way or the other. That's because it's a metaphysical problem. Humans exist in a physical space. The reason science and engineering have advanced is because we bracketed the problem of consciousness as something unanswerable. So it's possible that computers are conscious. It's possible that they're not. That's something I don't think anyone can answer.

How did science advance because the problem of consciousness is unanswerable?

Let me say it this way. We can get everything we want in the world without understanding where consciousness comes from. So why are we pouring all this energy into it? The only reason for doing it is because people have a religious spiritual impulse. It's like chasing God. We know where that got the monks in the Middle Ages.

Where did that get the monks?

It didn't get them to invent the laws of thermodynamics or invent computers or discover evolution by natural selection. It got them into a lot of arguments.

STORY SCIENTIST Angus Fletcher once worked in a neuroscience lab. "But I had this conversion moment where I thought, 'By studying the synapse, it's just too small to answer the big questions about narrative and life,' " he says. So he said goodbye to the lab and became a professor of English at Ohio State University, where he teaches "story science."

Most of our technology exists to domesticate space. Literature tackles the opposite: how to master ourselves.

I think humans enjoy having arguments about irresolvable problems. It gives us something to do. What's the best baseball team? What's the source of consciousness? But other than as a ludic pastime, consciousness is not something that I think anyone would seriously investigate scientifically.

Are you saying the study of metaphysics did not lead to developments in science?

That's exactly right. That's the narrative I would tell. In the Middle Ages, people were obsessed with the questions, "Who is God? What does God want?" But we discovered over time, starting with Machiavelli and moving into Francis Bacon and the 19th- and 20th-century scientific revolutions, that the human brain can't answer those questions. That's because the human brain has evolved to practice science. Science is about making hypotheses and testing them in our physical world. It's not about reaching the metaphysical. And literature is the origin of the modern scientific method.

Why do you call literature a technology?

A technology is any human-made thing that solves a problem. Most of our technology exists to master our world, to domesticate space. That's why we have smartphones and smart homes and satellites. Literature tackles the opposite set of problems: not how to master the nonhuman world but how to master ourselves. It wrestles with the psychological problems inside us. Grief, lack of meaning, loneliness—literature was invented to deal with these problems. To have happy and democratic societies, effective engineers and scientists, we need people who are joyful, not angry, who have a deep sense of empathy and purpose, who have an ability for logic and problem-solving. You get all these things from literature.

When you call literature a technology, it sounds like you're saying literature's a machine.

I *am* saying it's a machine! It's a machine designed to work in concert with another machine, our brain. The purpose of the two machines is to accelerate each other. Literature is a way of accelerating human imagination. And human imaginations accelerate literature. This technology is just sitting on our bookshelves and almost none of us are using it. Students now flee literature departments for the sciences and engineering.

In the past 20 years, enrollment in English departments has dropped by 25 percent, while enrollment in STEM classes has doubled. Why is that?

I can tell you exactly why that is. English literature is not being taught in a way that is connecting with people. We've been taught in school to interpret literature, to say what it means, to identify its themes and arguments. But when you do that, you're working against literature. I'm saying we need to find these technologies, these inventions, and connect them to your head, see what they can do for your brain. Literature isn't about telling you what's right or wrong or about giving you ideas. It's about helping you troubleshoot your own head.

SARAH LAGROTTERIA

Pragmatism isn't the enemy of beauty. Pragmatism allows beauty to happen.

The chapters in *Wonderworks* include fun names for the inventions of literature. The names include "Almighty Heart," "Serenity Elevator," "Sorrow Resolver," "Virtual Scientist." How did literature invent the virtual scientist?

A virtual scientist has no ego. Our brains are born scientists. From the moment we're born, we make hypotheses about what will happen if we do something. Then we test those hypotheses. We might say, "If I stick my hand in the fire, it might burn." And then we stick our hand in the fire. We're like, "Yes, that did burn." We're constantly running these experiments in our lives. We build stories and narratives as a way of organizing them. But what holds us back as scientists is our egos. That's because we just don't like to think we're wrong. Present someone with a piece of data that contradicts what they think and they will deny your data. They will bend your data to fit their hypothesis. This is an endemic psychological process of the human mind.

So the question is, "How do we become better scientists?" The way to do that is to remove our ego. Literature provides us the space to do that. What is Sherlock Holmes doing? Sherlock Holmes has given us a problem that we need to solve experimentally by positing hypotheses, by testing them. But we're not Sherlock Holmes and so it's not embarrassing if we happen to be wrong. Sherlock Holmes and tons of great detective fiction allow us to play virtual scientists by going into a space where our ego doesn't exist and we can practice our scientific method of making predictions and testing them.

You say pragmatism isn't bad for literature. I like that. What do you mean?

Pragmatism isn't the enemy of beauty. Pragmatism allows beauty to happen. If you're not fed, if you don't have a museum, if you don't have paints, if you don't have ink and printing presses, you don't have beauty. So let's acknowledge that pragmatism can work to support beauty and not displace or replace it. In the same way that the body supports the mind, let's feed the body. Let's see what literature can do for our physical nature.

Do you think a need for literature is baked into our evolutionary nature?

What I think is baked into our evolutionary nature is our need for meaning. "What was our origin? Where did the universe come from?" These are intrinsic questions in our brains. From the beginning, literature was the most effective way of answering them by spinning time backward and forward in fictional ways. Literature is very effective at generating a sense of wonder, which is the most basic and primordial spiritual experience. And we need wonder in our days.

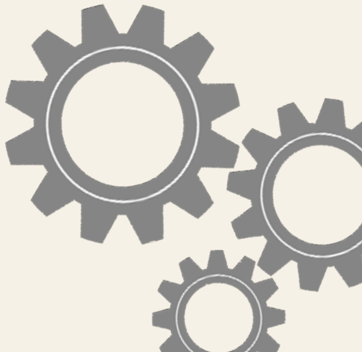
How would you respond to parents who might say, "My kids are never going to get a job studying literature. They need to study science, business, law. Why should they take literature classes?"

I don't think anyone *should* do anything. I'm not a totalitarian. I'm simply saying that if you decide that you want to take a literature class, it will enrich your life emotionally, intellectually, and creatively. It will allow you to imagine more dynamically. It will also allow you to problem-solve more effectively.

Independent of those things, narrative and stories are the most powerful thing that humans have. They are what have allowed Elon Musk to hijack our modern conversation about Mars and the future. That's all narrative. There's nothing actually new about SpaceX. It's just NASA. But Musk has been able to tell this story.

So if you want to be successful in business, if you want to be successful in science, if you want to be successful in anything, you need to understand stories and how they work. On a fundamental level, there's no better way to understand stories than through literature.

KEVIN BERGER is the editor of *Nautilus*.

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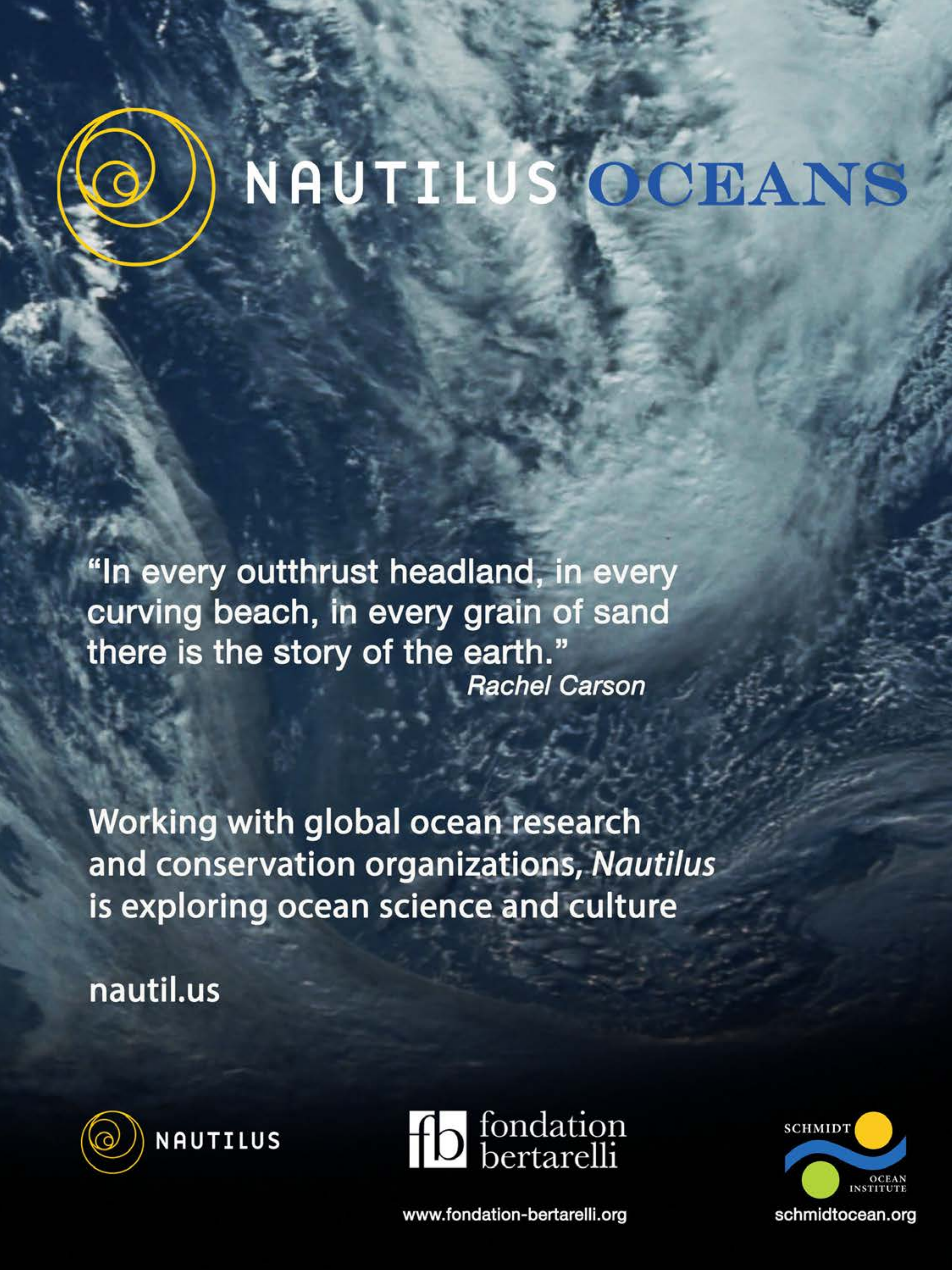
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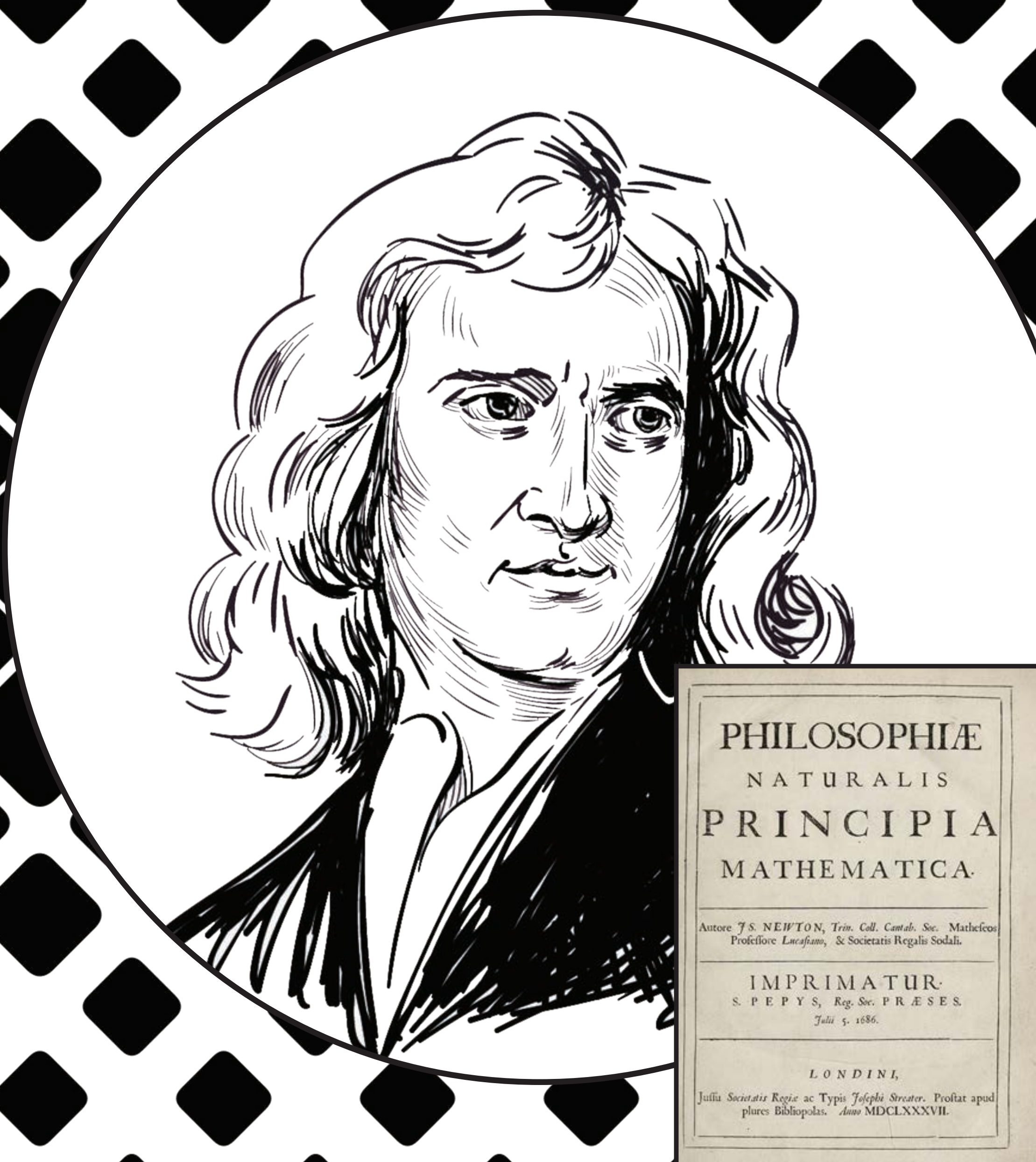

PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *JS. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

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Who Said Nobody Read Isaac Newton?

It's a myth that legendary works in science aren't read

BY CALEB SCHARF

THE CENTRAL UNIVERSITY LIBRARY at Cambridge, in the United Kingdom, is an imposing, towered building known affectionately for being called a "magnificent erection" by, before he became prime minister, Neville Chamberlain.[1] When I was a graduate student there, studying astronomy, rumors circulated within my cohort that if you went to the library and asked nicely, you would be allowed to examine, under supervision, a first edition of Isaac Newton's *Principia*, first published in 1687, complete with his own handwritten notes in the margins and inserted sheets.

All of which suggested a marvelous adventure. The *Principia*, or *Philosophae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*), has a mythological status. It was in fact three books: the first two covering the propositions and laws of motion, along with the innate attraction of all bodies to each other (gravitation), and the third being *On the system of the world*, in which Newton applied all of his insights to the detailed motions of the planets and their satellites, including our moon, the tidal motions, and even comets. These books laid out the quantitative foundations of classical mechanics, established the idea of gravity as a force sculpting the cosmos, and set up space and time as absolutes.

Sadly, I never quite got around to testing the rumor out for myself on the days I rode my bicycle past the library, hurrying to get out of the drizzle or morning fog. But the copy most certainly exists,[2] as do at least one or two others in Cambridge that have Newton's own post-publication additions. Part of the mythology surrounding Newton's magnificent thesis has been the notion that neither very many copies were printed for its first edition, nor was it at first very well read, or used. That latter supposition seems to relate to the received wisdom that the *Principia*, written in Latin, was such an incomprehensible monster of technical detail that very few would have been able to make much sense of it. Instead, the story goes, there was a slow burn—until the early 1700s, at which point Newton's corrected and improved later editions, along with a growing interest among scientists, began to finally have an impact.

Like many things in history, the precise origins of this myth are a little hard to pin down. But a recently published study, the result of more than a decade of work by the historians Mordechai Feingold, of Caltech, and Andrej Svorenčík, of the University of Mannheim, looks to shed light on this tale, and presents a dramatically updated narrative.[3] What seems to be emerging from this new census is a picture in which Newton's great work was actually widely, and immediately, read and discussed, perhaps even enjoyed, by both his intellectual peers and a larger population. It adds a new element to the story of how modern science developed, with more likely to come as the researchers dig deeper.

Supposedly the Principia *was such an incomprehensible monster that few could make much sense of it.*

Yet the idea that some of the central texts in the development of western science were either little distributed, or little read, has a certain strange draw. This same tale of scant readership was for a long time also applied to Nicolaus Copernicus' *De revolutionibus* (*On the Revolutions of the Heavenly Spheres*), the volume that was famously published more or less while he was on his deathbed, in the spring of 1543. It changed our view of existence by firmly removing Earth from the center of the cosmos, and by applying an inductive approach to science, where evidence came first, and hypothesis after.

The astronomer and historian of science Owen Gingerich, in his magnificent exploration *The Book Nobody Read*, published in 2004, went in search of answers to this puzzling contradiction: the idea that Copernicus's work was little read and little understood, yet so influential. What he found was not only 276 first editions (a perfectly respectable number for the time) but that a wealth of copies came with the handwritten notes of their readers, many of whom represented the astronomical and intellectual movers-and-shakers of the period. Far from being a 16th-century coffee table obscurity, *De revolutionibus* and the proposals it contained had clearly been a critical, and well-read, reference point.

This kind of narrative, of the unread masterpiece, doesn't go away though. Even with more modern texts, aimed at quite general audiences, the same sort of tales or myths seem to develop. For a while it was (and perhaps still is[4]) positively fashionable to admit to having a copy of Stephen

Hawking's *A Brief History of Time* but to have "not really read all of it." As if that somehow conferred greater status to a book, one that explored the origins and evolution of the universe, as well as to your fortitude for at least having given the story a shot.

In Newton's case, some of our modern interpretation of the *Principia*'s dispersal appears to stem from a 1953 study by Henry Macomber[5] (curiously then at the Babson Institute in Massachusetts, a school focused on business and finance) that made a census of who owned the first editions. That study sided with estimates made in the late 1800s to claim that fewer than 250 copies (based on 189 actually identified ones) had ever existed. Given the well-known birthing pains of *Principia* itself, which took the gritted teeth and persistence of astronomer and comet-finder Edmond Halley to squeeze action out of Newton, and a variety of elitist 18th- and 19th-century anecdotes about the material's impenetrability, it's not hard to see how the idea of a "difficult," little-read book took root.

Yet there had to be a rather larger print run, others have suggested, based on the obvious incompleteness that comes from only counting the copies that still exist today. To try to get to the bottom of this, Feingold and Svorenčík undertook an astonishingly systematic and exhaustive preliminary survey spanning some 27 countries and their libraries, private owners, and booksellers. The survey's discoveries add up to 387 identified copies of the first edition of *Principia*, indicating a print run that was likely more in the range of 600 to 650 copies—a far cry from a couple of hundred. But the most wonderful results and insights promise to come from future analyses of who owned the books, how often they exchanged hands, and what people's reactions were from the notes written in the pages.

When new insights to the nature emerge, they are stress-tested by their correspondence to reality.

The reality in all of these cases has to be that, in the end, important works do most certainly get read, or else how would we ever consider them important? But the avid readers, the marginalia scribblers, the thinkers, don't go about telling their gossipy cocktail partners that they're really relishing Newton, or Copernicus. Instead they're simply busy stretching their minds, seeking insight and inspiration for their own works that will, in turn, help dilute and propagate the original breakthroughs that were—by the nature of being pioneering—awkward, dense, tricky,[6] and extremely challenging.

By contrast, it's the complainers and (to use the modern term) trolls who perhaps make the most quotable and long-lasting statements about their confusions. In Feingold and Svorenčík's examples they describe incidents like that of the elderly mathematician and natural philosopher Gilbert Clarke, who wrote to Newton asking him to assist with understanding *Principia*'s contents, and complaining about why it wasn't easier to understand; stating "you masters doe(sic) not consider the infirmities of your readers, except you intend to write only to professours or intended to have your books lie, moulding in libraries or other men to get the credit of your inventions."[7]

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It was (and perhaps still is) fashionable to admit to having a copy of Stephen Hawking's A Brief History of Time.

It's an amusing, if perhaps horrifying, thought experiment to imagine *Principia* showing up on Amazon today and running the gauntlet of the comment system. "Why is this thing written in Latin?" "It would help if it wasn't so long." "I can't understand this, why are scientists so bad at explaining things?" "I don't buy this idea of gravity at all, what nonsense!" Four centuries from now the historians of science would be examining terabytes of Facebook and Twitter records to try to understand whether or not anyone actually read this monumental work.

There is a deeper, and far more optimistic lesson in all of this. We are a species of information and ideas, propagating these things through time and space in our genes, brains, and externally instantiated data.[8] When new insights to the nature of the world emerge, they are stress-tested by their correspondence to reality, and their reception by our spindly neurons. Science of the past 400 years is a particularly efficient and demanding sieve for what works and what doesn't. Science also doesn't stand isolated from the societies that have generated it. Scurrilous rumors about nobody reading certain books, or ideas that are too hard to come to grips with, are a part of that social element, and they can be seen as part of the sieve, helping distill and disperse the best of our insights.

Indeed, if you follow up on the tale of crabby old Gilbert Clarke in the 1600s, it turns out that Newton took his complaints to heart and made corrections in the second edition of *Principia*, based on those prompts. But we tend not to hear much about these improvements to readability. The myth of his "impossible" book actually reinforced its importance; after all, it must be *really* important if it's that tough to understand.

In that sense, there is a kind of natural selection taking place for human information itself, like a bottleneck or founder effect in biological evolution. The most useful or important information tends to propagate forward, but in order to do so it may have to be squeezed and recast into better-digested pieces that can go on to populate human minds. Consequently, we feel compelled to, at first, convince ourselves that *Principia* or *De revolutionibus* were too much for most people—yet somehow the ideas stuck because they were so extraordinarily powerful.

In retrospect, my not parking my bicycle outside of the Cambridge library and going in to look at Newton's handwritten notes wasn't actually a gross personal failure. I already had knowledge of the *Principia*'s essential contents. I was a perfect example of the astonishing success of the mythology of this impossible, little-read book, its actual wide dispersal and translation, and the scientific revolution that it set in motion. At least that's my story.

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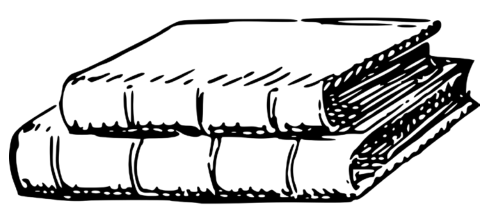

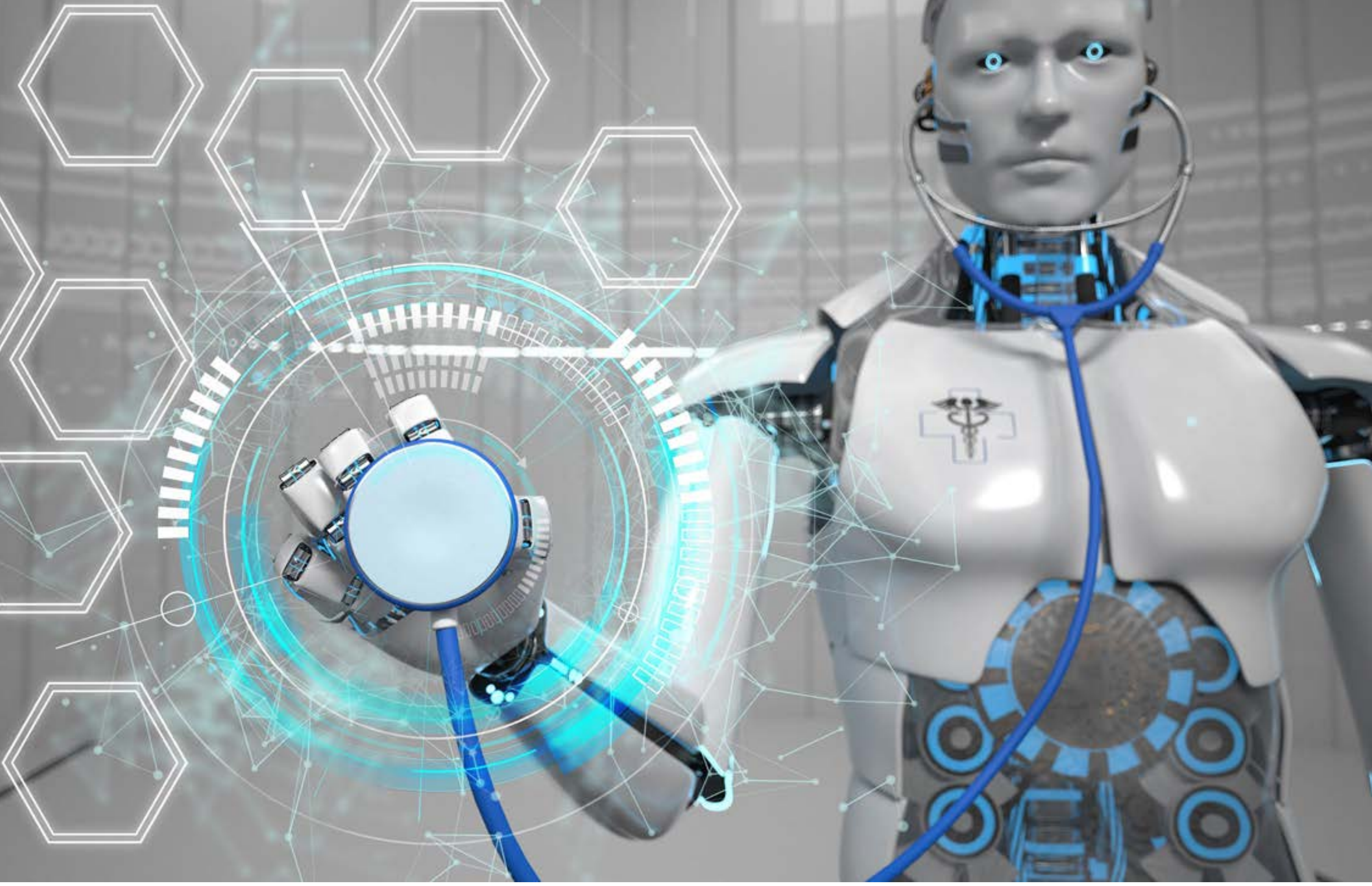

ALEXANDER LIMBACH / SHUTTERSTOCK

The Doctor Will Sniff You Now

Step aside, Dr. House, Deep Nose will one day be the best diagnostician in medicine

BY LINA ZELDOVICH

IT'S 2050 AND YOU'RE DUE for your monthly physical exam. Times have changed, so you no longer have to endure an orifices check, a needle in your vein, and a week of waiting for your blood test results. Instead, the nurse welcomes you with, "The doctor will sniff you now," and takes you into an airtight chamber wired up to a massive computer. As you rest, the volatile molecules you exhale or emit from your body and skin slowly drift into the complex artificial intelligence apparatus, colloquially known as Deep Nose. Behind the scene, Deep Nose's massive electronic brain starts crunching through the molecules, comparing them to its enormous olfactory database. Once it's got a noseful, the AI matches your odors to the medical conditions that cause them and generates a printout of your health. Your human doctor goes over the results with you and plans your treatment or adjusts your meds.

That's how Alexei Koulakov, a researcher at Cold Spring Harbor Laboratory who studies how the human olfactory system works, envisions one possible future of our healthcare. A physicist turned neuroscientist, Koulakov is working to understand how humans perceive odors and to classify millions of volatile molecules by their "smellable" properties. He plans to catalogue the existing smells into a comprehensive artificial intelligence network. Once built, Deep Nose will be able to identify the odors of a person or any other olfactory bouquet of interest—for medical or other reasons. "It will be a chip that can diagnose or identify you," Koulakov says. Scent uniquely identifies a person or merchandise, so Deep Nose can also help at the border patrol, sniffing travelers, cargo, or explosives. "Instead of presenting passports at the airport, you would just present yourself." And doctor's visits would become a breeze—literally.

Deep Nose matches your odors to the medical conditions that cause them.

WHAT CAN ONE'S ODOR tell about one's health? Apparently, a lot. "The information that can be picked up from the airborne molecules is amazingly rich," says Dmitry Rinberg, also a former physicist and now a neurobiologist at New York University who collaborates with Koulakov on olfactory research. "It's so informative that you can tell what kind of beer people drank at a bar last night." Odor can reveal other things happening with the body, he adds. "So we are trying to use this information for odor-based diagnostic approaches."

Recent research finds that many diseases, including cancer, tuberculosis, and Parkinson's, can manifest themselves through volatile compounds that change the person's scent. Our bodies release certain metabolites—products of our metabolic activities. Some of these molecules are volatiles and become part of our scent, or "odorprint." When we become sick or start developing a disease, our metabolic processes start functioning differently, emitting different volatile molecules or mixtures of them, so our odorprint changes too. "These molecules carry information about our state of health," Koulakov says. For example, patients with Parkinson's disease produce an unusually high amount of sebum,[1] a waxy lipid-rich biofluid excreted by the sebaceous glands of the skin, which sensitive noses can detect. Deep Nose could grab this information from the thin air. That could allow physicians to detect disease sooner, easier, and perhaps avoid some invasive diagnostic procedures. "It would essentially revolutionize the diagnostics system," Koulakov says.

Hippocrates, Galenus, Avicenna, and other physicians of ancient times used their noses as diagnostic tools. A wound with a nasty smell could mean it was infected. And bad breath signaled a host of ailments. Today, however, physicians don't sniff their patients—because humans generally stink at smelling. In fact, we are worse than our ancestors. Our primate predecessors sported about 850 olfactory receptor types, but we retained only 350 functioning ones, which in various combinations allow us to smell an astronomical amount of odors. (The rest of them simply don't work. "They are the remnants of our former glory," Koulakov quips.) Meanwhile, dogs have about 850 receptor types and mice about 1,100 or 1,200, so they are capable of discerning a much greater variety of smells—including those produced by the malfunctions of our bodies.

Scientists now use that animal olfactory wealth to diagnose disease—with some documented success and peer-reviewed studies. Recently, a group of scientists from several research institutions presented their results of training three beagles to sniff patients' blood samples and detect lung cancer cells in them with 97 percent accuracy.[2] A study published in *British Medical Journal* stated that dogs were able to detect colorectal cancer by smelling stool.[3] Another paper in *BMC Cancer* described dogs smelling out ovarian cancer.[4] And African giant pouched rats had been taught to work as "tuberculosis diagnosticians" in Sub-Saharan Africa, sniffing sputum samples from patients. Microscope detection accuracy can vary from about 20 to 80 percent. The rats' noses helped improve detection by up to 44 percent.[5]

But animal diagnosticians have their problems. First, they must be trained, and training large numbers of animals that don't live very long is expensive, time-consuming, and somewhat futile. Plus, every time you'd want to add yet another disease scent to their analytic arsenal, you'd have to train all of them again. "The use of animals for actual diagnostics is very limited," Rinberg says.

That led scientists to ponder the possibility of an electronic nose instead. It would be far more economical to build an artificial sniffer apparatus that wouldn't die after a few years, with standard software that can be updated regularly across the board. And that's how Koulakov envisions Deep Nose—an electronic olfactory AI that can function as a nose that picks up scents and as a brain that interprets them. That, of course, is no easy feat. Deep Nose is modeled after the neuro-machinery of the human brain, but scientists have yet to figure out how the human brain identifies one scent from another.

BIOLOGICALLY, THE ACT OF SMELLING is more complex and less understood than our ability to see. Recognizing a scent is a precise and intricate process in which chemistry, biology, and physics must play together in a synchronized concerto—whether you're relishing the aroma of a rose or pinching your nose at a pile of dog poop.

Inside your nasal cavity, millions of olfactory neurons are waiting for the next smelly molecule to fly in. These neurons have microscopic finger-like protrusions called cilia, which float in the mucus covering the surface of the nasal epithelium. The neurons' other ends,

Dogs have been taught to smell cancer, and rats have been taught to work as "tuberculosis diagnosticians."

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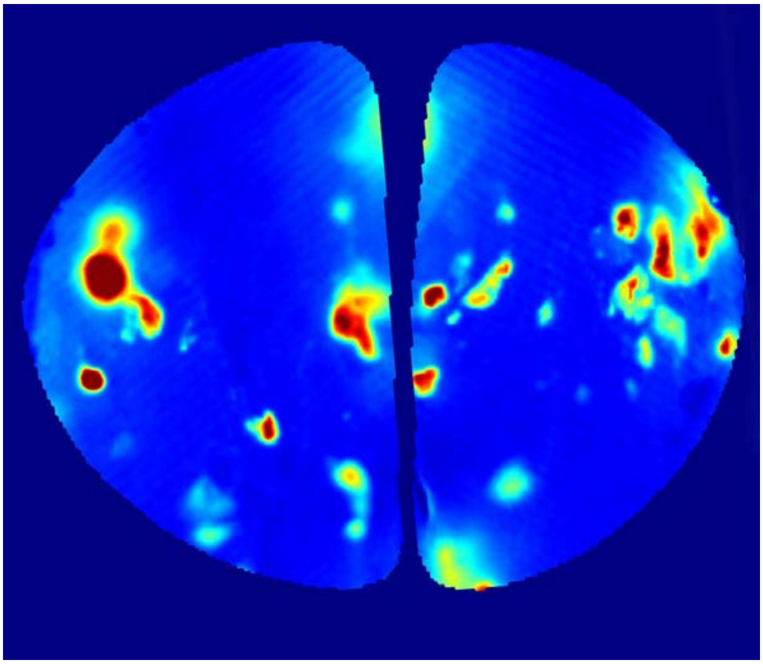

SIGHT OF SMELL This image shows a rodent's brain as it smells Methyl valerate. The oily liquid, used in fragrances, gives off a fruity odor. The neurons contain fluorescent protein that changes color when a neuron is active. Darker red colors correspond to more activity.

called axons, stretch upward, passing through special passages inside the skull all the way to the brain, leading to the region called the olfactory bulb, named so for its onion-like shape. When molecules fly into our nose, they bind to the cilia, and the neurons send this information to the olfactory bulb, which interprets it, resulting in our sensation of the smell. It would also pass these signals to the olfactory cortex, whose neuromachinery would determine the quality and the concentration of the smells.

Some molecules bind to certain receptors but not to others. Depending on the specific combination of receptors the molecules lock onto, we would smell roses or dog poop. But even that seemingly simple molecular handshake remains mysterious. Some scientists believe in the "steric binding theory," which states that the molecules fit receptors' distinct physical shapes. Others support the "vibrational theory" that purports that olfactory receptors detect the molecules' vibrational frequency and "translate" them into odors. "The steric theory suggests that there is a binding pocket of a particular shape, and some molecules will fit there, while others may swim away in the mucus," Koulakov says.

Regardless of which theory proves correct, Deep Nose builders still face a huge challenge. The nose part, which would mimic the neuronal binding action, will require chemical sensors. These sensors will interact with the flying molecules—whether by binding or a different method—and detect their presence. The sensors will then send electrical signals to the electronic brain—the Deep Nose network that will interpret what molecules have been detected. Koulakov envisions it functioning as a network of multiple layers that will be able to recognize different parts of the molecules and different chemical groups within them—just like different neurons react to the presence of different molecules inside biological brains.

COURTESY OF DR. HIRO NALKAYAMA, RINBERG LAB, NYU NEUROSCIENCE INSTITUTE

Luckily, researchers can see how that neuronal activity happens inside living brains. Modern technology allows one to peek inside the brain, seeing what olfactory receptors activate in response to what odors. That requires brain surgery and genetic manipulation, so it's not possible to do in people, but mice and rats can help. That's where Rinberg's lab comes in. His team uses genetically modified mice whose olfactory neurons are tinted with fluorescent proteins that light up when they engage in response to an odor. The team can watch that process through a window implanted into the rodents' skulls. "We genetically encode mice so they are born with fluorescent proteins in the olfactory bulbs of their brains—and we can see how the olfactory neurons light up," explains Rinberg. "It can let us see that a rose, for example, excites receptors number 27, 72, and 112, while dog poop excites a different subset of receptors. But who knows, we might also find that roses and poop actually activate some common receptors!"

Systematically gathering these neuronal activation patterns would inform scientists about combinatorial codes of receptors that activate in response to everything from roses to poop and from coffee to the wet dog smell—and all other things in the smelliverse. Similarity, specific neuronal combinations would light up in response to specific molecules, including the metabolites we produce in health and disease.

Diseases will likely manifest themselves by the presence of multiple volatile molecules—a cocktail of them, Koulakov thinks, so here rodents' abilities would be particularly helpful. Their superb olfactory receptors, which outnumber ours threefold, would let them smell many more mixtures than we can, so they can help train Deep Nose on various smells that we emit but can't detect on our own. Just like rats have been trained to detect our TB, they can be trained to sniff our tumors, while researchers can map the exact neurons that light up in their brain in response to different cancers' smells. "Once we collect the info about what neurons activate in responses to what smells in mouse brains, we can train Deep Nose on that data," Koulakov says. "It is important to map this 'olfactome.' "

Science is still decades away from electronic olfactory diagnostics. However, a small army of rodents with neurons that glow in response to certain smells could help detect health ailments in about 10 years, Koulakov estimates. That's because the technology needed for observing their colorful neuronal responses already exists, but the technology necessary for mimicking neuronal binding to flying molecules—the chemical sensors to detect our metabolites—is yet to be created. But once this is accomplished, building an electronic nose to sniff out health problems would be fairly straightforward. "Our evolution may not have designed us to diagnose disease," Koulakov says, "but we can design a software that can do so."

LINA ZELDOVICH grew up in a family of Russian scientists, listening to bedtime stories about volcanoes, black holes, and intrepid explorers. She has written for *The New York Times*, *Scientific American*, *Reader's Digest*, and *Audubon Magazine*, among other publications, and won four awards for covering the science of poop. Her book, *The Other Dark Matter: The Science and Business of Turning Waste into Wealth*, will be released in October 2021 by Chicago University Press. You can find her at LinaZeldovich.com and @LinaZeldovich

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We Need More Feminist Dads

It's not easy to overcome the masculine conception of fatherhood

BY JORDAN SHAPIRO

O**NE OF THE KIDS** in my house feels bad for people named Karen. He announced it at the dinner table. “They’re not all annoying, or racist, or anti-vaxxer,” he said. “They don’t all demand to speak to the manager. How do you think the good Karens feel?”

I pass a plate of steamed broccoli to my partner, Amanda, and explain to all four kids that while the Karen meme has been controversial,[1] and may indeed be a misogynist tactic[2] used to invalidate women’s voices, it’s not an oppressive slur. Nobody named Karen faces systematic discrimination on the basis of their birth name. So, there’s no need for him to feel bad.

He’s been watching extreme partisan politics play out on the news, reading books about race and gender, and he’s struggling to work out the nuance of who’s allowed to be a victim. Everyone claims to be silenced, censored, and canceled! Whose plight is real? It’s hard enough for the grown-ups to figure it out; imagine how confused the 13-year-olds must be. What counts as legitimate prejudice and stereotype? Where are the boundaries of cultural appropriation? When are sensitivity and tolerance required, and when is edgy humor good-natured and inoffensive? I do my best to address his concerns, to guide his thinking, because I’m a proud feminist dad and I’m trying to raise little social justice warriors. I slice into a panko-breaded chicken cutlet, remind the children to chew with their mouths closed, and reflect on how complicated fatherhood has become these days.

According to a 2015 Pew report, 57 percent of fathers in the United States identify parenting as something “extremely important to their identity.”[3] But the current conception of fatherhood is misaligned with their reality; it fails to provide men with positive aspirational models, meaningful opportunities for reflection, or the healthy psychological grounding necessary to optimally prepare their children for the 21st century. At the root of the problem is Dad’s inability to escape constrictive and outdated ideas about gender.

Take the difference between gender and sex. Gender is the word that’s often used to describe the traits, characteristics, experiences, and social expectations that are associated with identity. Sex is the word used to describe one’s biological anatomy. Many parents try to be intentional when it comes to how we represent culturally constructed gender norms with our children. We do our best to avoid sorting playtime into pink and blue categories. We try not to make stereotypical assumptions about our kids’ preferences, aptitudes, or emotional constitutions. We recognize that if we assume sex governs psychology—that boys will innately conform with certain social conventions and girls will be drawn toward others—we’re engaged in a fallacy of biological determinism.

Feminist parents are making progress. We still have a long way to go, as evidenced by the gendered toy aisles in most big-box retail stores, but at least the conversation has gone mainstream. Unfortunately, we can't say the same when it comes to Dad's identity. Scientifically invalid assumptions about manhood continue to contour the fatherhood experience. Despite decades worth of research to the contrary, we can't help but take it for granted that certain traits track with biological sex—as if men are from one galaxy, and women from another (I guess gender-nonconforming individuals must be either alien or lost in space).

This binary way of thinking—conflating sex with gender—is not only wrong, but also nefarious. It serves to validate male privilege by asserting that existing inequities reflect nature. I call it "locker-room gender essentialism" because it reminds me of the so-called facts about the sexes that middle-school boys expounded on when the girls weren't around. We were being socialized to believe that a lopsided power dynamic is immutable. Bad science can become a mythology that shapes our adult lives. Consider the entitlements that patriarchal societies bestow on men who are assertive and dominant. These behaviors are often lauded as a male evolutionary imperative. Dads are told it's their duty to protect a clan. It's the natural order of things, the essence of fatherhood. "Survival of the fittest" becomes an excuse for ends-justify-the-means and winner-take-all competition.

In truth, natural selection works a lot like parenting: Adaptability produces much better outcomes than rigidity. Everything you've heard about fixed versus growth mindset, intrinsic versus extrinsic motivation, and positive versus negative reinforcement points in this direction. Carrots work better than sticks. Spanking causes more harm than good. Shame leads to long-lasting psychological trauma. Punishments like time-out and grounding are only effective as interventions, not as a way to encourage long-term behavioral change. The old fear-based, father-knows-best, disciplinary methods don't work. You and I turned out alright despite—not because of—Dad's constant scolding and occasional smack.

Notwithstanding the scientific consensus, fathers still struggle to evade the intense pressure they feel to conform with outdated and sexist cultural norms.

Bad science can become a mythology that shapes our adult lives.

Gendered parenting expectations are not only the go-to punchlines for stand-up comedians, but also the taken-for-granted best-practices when it comes to childrearing: Mom should nurture unconditionally and Dad should withhold affection—his "tough love" mirroring the real world's apathy and indifference. Motherhood equals abundance, fatherhood equals scarcity. Especially when it comes to raising sons, Dad still believes the Oedipal fallacy that maternal dependence must be disrupted by a reality that's hard, cold, and mythologically masculine. *A boy needs his dad to be the initiating gatekeeper to a dog-eat-dog world!* As sociologist Michael Kimmel explains, "We've constructed the rules of manhood so that only the tiniest fraction of men come to believe that they are the biggest of wheels, the sturdiest of oaks, the virulent repudiators of femininity, the most daring and aggressive."[4]

Dads perpetuate this lie each time they buy selvedge denim, bottled-in-bond bourbon, or Chromexcel leather work boots—coded signifiers of status—which subtly demonstrate commitment to an old-school masculine persona. The famous Swiss psychologist Carl G. Jung used the term "persona" to designate an individual's outward-facing attitude. He described it as "a kind of mask, designed on the one hand to make a definite impression upon others, and, on the other, to conceal the true nature of the individual." Jung knew that we all metaphorically dress in uniforms and costumes designed to show that we are the rightful players of the everyday parts we intend to enact. But often, we over-identify with the avatars we've created. We start to believe that we are what we pretend to be. "Masculinity," author Chimamanda Ngozi Adichie wrote, "is a hard, small cage, and we put boys inside this cage."[5]

The most familiar model of the nuclear family still includes paternal roles which are inherently patriarchal, and often misogynist.

You probably think I'm moving toward a familiar argument about the problems with toxic masculinity. I'm not. The truth is I find a lot of the contemporary rhetoric claiming cisgender men need more opportunities to express vulnerable emotions to be severely oversimplified. To put it crudely, it often sounds to me like a bunch of boys whining, "Somebody please, hold my balls while I cry!" Let's be honest: If you already have unwarranted access to everything—including the authority to construct your own narrative—do you really need explicit permission to attend men's groups, wilderness retreats, and cathartic drum circles? Isn't that just claiming yet another privilege? An entitlement? I think so.

The toxic masculinity diagnosis was formalized in 2018, when the American Psychological Association issued its first *Guidelines for Psychological Practice with Boys and Men*. That document says that men are so afraid of appearing weak or "feminine" that they bury their feelings; they over-conceal. This can lead to mental health issues, cardiovascular problems, substance abuse, violence, incarceration, early mortality, and more. Surely, we'd like to avoid these negative outcomes. But the toxic masculinity framework doesn't adequately address the specific problem that today's fathers face.

Economic, technological, political, and social norms are all changing. And fathers are stuck in a bind because the most familiar model of the nuclear family still includes paternal roles which are inherently patriarchal, and often misogynist. Many dads may want to see themselves as modern, evolved men. They're legitimately concerned about gender equity. They try to be different from previous generations. In 2016, dads spent triple the number of hours per week involved in childcare as fathers did in 1965.[3] They also accounted for 17 percent of all stay-at-home parents, up from 10 percent three decades earlier.

Still, research confirms that they regularly reproduce the same old sexist labor disparities at home. According to Darcy Lockman, author of the 2019 book, *All The Rage: Mothers, Fathers, and the Myth of Equal Partnership*, even working mothers "devote twice as much time to family care as men." Early research suggests that this divide is widening due to pandemic pressures. But the coronavirus may just be exposing patterns that already existed. In her book, Lockman describes how expectant fathers told researchers that they anticipated their wives would shoulder more of the new childcare responsibilities. Six months in, those same dads reported that they did even less work than they initially predicted.

Even in households with older kids and teenagers, the same imbalance remains. Whether they're married or divorced coparents, mothers are far more likely than fathers to take responsibility for envisioning, planning, organizing, managing, and executing the logistics of their children's lives. They coordinate transportation to and from soccer games, gather supplies for school trips, keep kids focused on homework assignments, prepare for birthday parties and sleepovers, make appointments for pediatric checkups, and more, even as they hold down full-time jobs. Clearly, the requisite skills needed to accomplish all of these tasks don't track neatly to stereotypically "feminine" competencies. But we all take the unspoken (and oftentimes spoken) sexist expectations of the patriarchal nuclear family for granted.

As Eve Rodsky, author of *Fair Play: A Game-Changing Solution for When You Have Too Much to Do (and More Life to Live)*, puts it, Mom is considered the "she-fault" parent.[6] Research confirms the bias. Fifty-three percent of Americans say that, breast-feeding aside, mothers do a better job than fathers at caring for a new baby.[7] Forty-five percent say that mothers and fathers do it equally well. Only 1 percent say that fathers do it better. Folks just assume that biological sex determines one's competence at caretaking, making little allowance for

You and I turned out alright despite—not because of—Dad's constant scolding and occasional smack.

variations among individuals. Reality is more nuanced. As a 2019 paper in the *Journal of Neuroendocrinology* noted, "Given that primary caregiving fathers do not experience the same biological changes that primary caregiving mothers do during pregnancy, birth or lactation, it is remarkable to observe how the paternal brain may, to some degree, adapt to the demands of a primary caregiving role."[8] The "parental brain," in other words, is more flexible than you might suppose, being "capable of adapting to the social environment in order to better assume specific caregiving responsibilities."

Today's young dads tend to be enthusiastic parents, but only 39 percent believe they're doing a "very good job" raising their kids; compare that with 51 percent of mothers. Similarly, a 2017 survey found that 63 percent of fathers feel like they don't spend enough time with their children.[3] They cite work obligations as the primary obstacle. There's fierce pressure economically, to provide for one's family, and socially, to conform with the expectation that men be hardworking and persistent breadwinners. That's the way we're taught to establish our father-figure credentials. We should work weekends and overtime, ruthlessly pursuing wealth and status, to demonstrate our commitment to family.

Today's fathers are caught in a classic case of cognitive dissonance. Two fatherly inclinations are in conflict. Inconsistent thought patterns lead to behaviors and attitudes that both serve and anguish the individual. To go all in on feminism seems to betray the customary good dad story. To go all in on the prevailing good dad story undoubtedly betrays feminism. And until we work it out for ourselves, we won't be able to guide our children. We can't mentor them as they work out the nuances of social injustice. We can't model inclusive attitudes. We can't engage them in 21st-century discourse at the dinner table. Or at least, we can't do it as effectively as we might like until we're willing to reimagine fatherhood as less dominant, less paternalistic, and not necessarily masculine.

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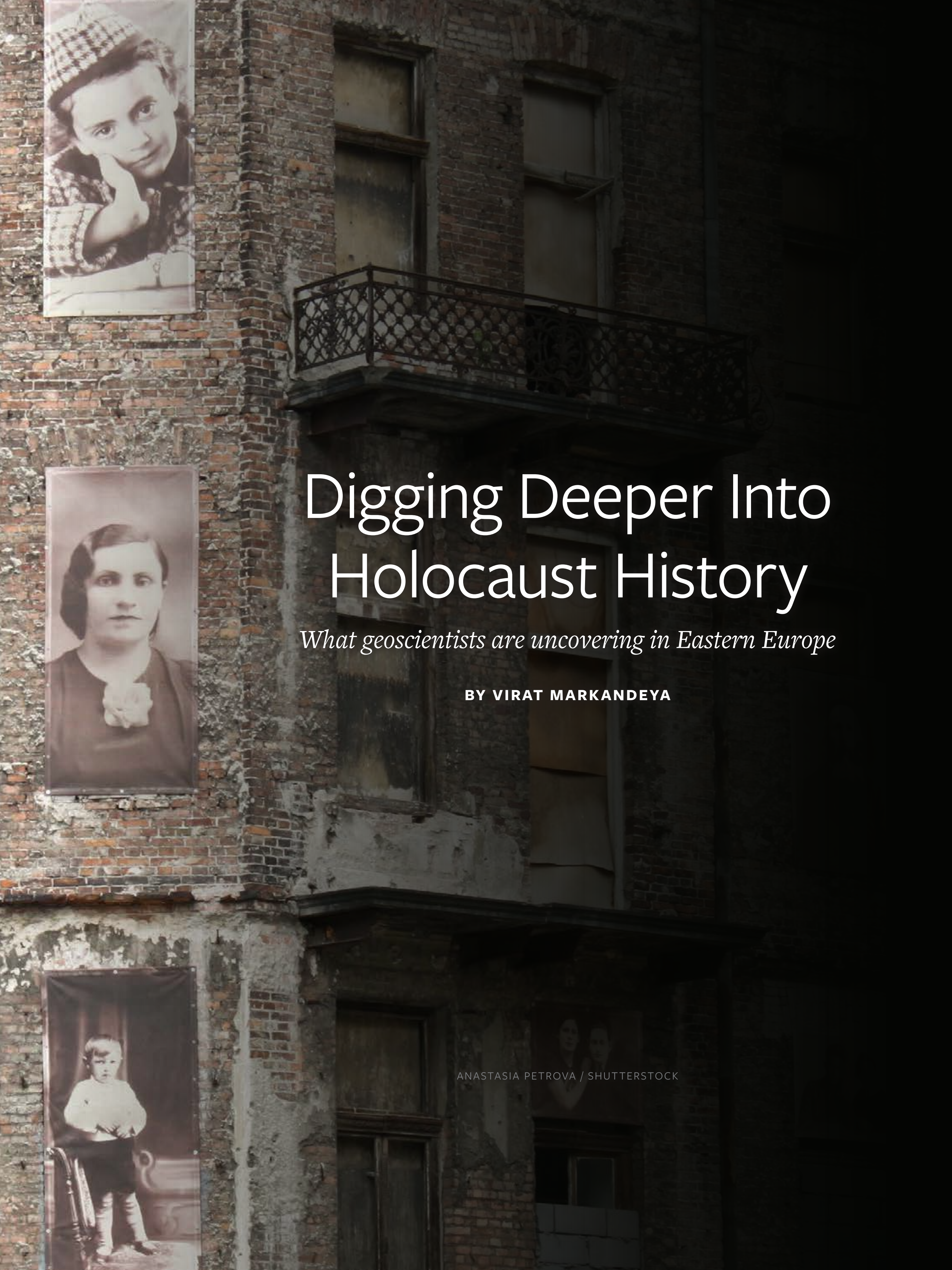

Digging Deeper Into Holocaust History

What geoscientists are uncovering in Eastern Europe

BY VIRAT MARKANDEYA

ANASTASIA PETROVA / SHUTTERSTOCK

ON A TRIP to Warsaw, Poland, in 2019, Richard Freund confronted the history of resistance against the Nazis at a Holiday Inn. Freund, an archaeologist, and professor of Jewish Studies at Christopher Newport University in Virginia, was led by the hotel manager into the basement. "Lo and behold," Freund says, a section of the Warsaw Ghetto wall was visible. Freund was in Warsaw accompanied by scientists from Geoscientists Without Borders, a nonprofit group whose mission includes investigating archaeological sites and working to mitigate natural disasters like earthquakes and tsunamis.

The geoscientists were helping Freund pinpoint the location and contents of underground bunkers, where hundreds of Nazi resisters, led by 24-year-old Mordechai Anielewicz and his girlfriend Mira Fuchrer, plotted to combat the deportation of Jews to death camps. The rebellion erupted in the Warsaw Ghetto Uprising of 1943, the largest Jewish revolt in World War II. The resistance lasted nearly a month. During the battles, Nazis funneled poison gas into the underground bunkers, killing many of the rebels and driving others to escape through sewer tunnels. The Nazis crushed the uprising and razed the Warsaw ghetto. Tens of thousands of Jews either died in the battles, were executed, or were deported to death camps.

The history of the uprising was written in part by those who escaped. "They tell us what happened in that final moment," says Freund, who has led archaeological investigations into Jewish history in Israel and Europe. But the story of the Warsaw uprising, and the Holocaust, is not complete. Holocaust survivors and their stories are dwindling. Now geoscientists have stepped in to fill in the historical gaps. By employing geophysical mapping and soil sampling, among other techniques, they have located mass grave sites—there are an estimated 200 such sites in Lithuania alone—corroborated testimonies of daring escapes, and unearthed the remains of a once-thriving culture.

This summer, Freund plans to tread carefully beneath underground sewer lines in Warsaw to explore Mila 18, or "Street 18," the bunker that served as the headquarters for the Ghetto resistance fighters. Determining what remains in the bunker is difficult. When Warsaw was rebuilt after the war in the Soviet era, they tamped down the remains, poured cement for a foundation, and built on top. Thanks to a technique that images the subsurface after an electrical current is passed through—Freund calls it "pinpoint archaeology"—geoscientists identified metal objects in the bunker. Freund is anxious to discover if the metal is just sewer pipes, or if it could be stoves the fighters used to keep warm, or reinforcements to tunnel walls, or even arms caches.

> *The story of the Warsaw Uprising, and the Holocaust, is not complete. Geoscientists have stepped in to fill in the historical gaps.*

"Science is the next frontier that will speak about these sites," Freund says. Geophysical techniques provide a way to locate and preserve sites that have been built over, as is often the case in Holocaust sites across Europe, even locating them under the canopy of vegetation. While certain sites will be excavated, the process of discovering them does not have to be destructive, as with traditional archaeology. Using noninvasive techniques means archaeologists can hold history in situ. Such noninvasive methods are a matter of being sensitive, too. "These are mass graves of people who are victims," Freund says. "They have been victimized once and we don't want to disturb them again by disturbing their burials."

THE GREAT SYNAGOGUE in Vilnius, Lithuania, was a legendary house of prayer known as "Jerusalem of the North." It was built of wood in the 1500s and revamped by Italian architects with brick in the 1700s. The synagogue was part of a complex with a library, study rooms for scholars, and ritual baths with a stove for heating the water. The synagogue also had a secret. To circumvent an ecclesiastical rule that forbade buildings higher than the local church, "the Jews, instead of building up, built down," Freund says. Worshipers walked down two flights of stairs to get to the main hall. When they looked up, the synagogue was five storeys high.

During a rampage, Nazis burned down the synagogue. After the war, the Soviets laid a cement foundation on the area and built a school and playground on top of it. In 2015, Jon Seligman of the Israel Antiquities Authority, whose family was from Lithuania, instigated a search. He enlisted physical geographer Harry Jol of the University of Wisconsin, Eu Claire. Jol began a search on the playground with ground-penetrating radar. The device emits an electromagnetic pulse and records the echo among the subsurface stratification, building an image of the underground. The technique played a crucial role in convincing the authorities to allow excavation on the school premises.

Paul Bauman, technical director of geophysics at Advisian, a consulting firm, led further explorations of the site. (In 2020, Advisian, with support provided by Geoscientists Without Borders, published a report of the geoscientists' investigations of Holocaust sites—a key source for this article.) What worked in the geoscientists' favor, Bauman says, is the composition of the Earth in Lithuania. It's a relatively homogenous subsurface comprised of glacial fluvial outwash. Much of the Baltics "is a bit of a giant sandbox," he says. "That makes it well-suited to radar," which has an easier time identifying anomalies because "anything that wasn't sand really stood out."

Employing techniques of electrical resistivity tomography and "induced polarization," Bauman and his colleagues located precise targets for the archaeologists. Induced polarization images the subsurface in terms of its "chargeability." Chargeability is loosely the ability of the subsurface to store charge, even if it is for milliseconds. This is useful for pinpointing metal objects, such as a heating stove, which geoscientists discovered at the Great Synagogue. In the chargeability plots made by the geophysicists before excavations, the metal object stands out at a particular depth. In "resistivity" plots, on the other hand, so-called "void spaces" show up. At the Great Synagogue, such void spaces, "a lot of air space with collapsed debris," Bauman says, corresponded to a cellar under the synagogue's Bimah or altar.

Discoveries made in the area include a Hebrew inscription incised with gold-fleck still on the letters, coins dating from Napoleonic times, tiles with decorations, a petal of a metal candelabrum, and a book stuck into a wall. Exploration continues this summer. Freund says he hopes to discover the contours of the original wood construction. "You're looking at time capsules below the surface, and each one of them tells you about the population of Jews within that time," he says.

DEATH FORT Geophysicist Paul Bauman collects data to locate burial trenches and remains at a "death fort" in Lithuania, where Nazis killed tens of thousands of Jews. Working in the area, which today is an open park, "was something very sensitive," Bauman says.

MOST OF THESE TIME CAPSULES tell horrific stories. On a cold and cloudy summer day in 2019, Bauman collected soil samples from mass graves in Kaunas, Lithuania. He was working in an area known as the "Battlefield," fallow land at Fort IX. When Lithuania was under Tsarist Russia rule, it constructed nine forts to barricade the city from Prussian invasions. In their stampede across Europe, Nazis took over Fort IX and turned it into a "death fort," where they killed 50,000 Jews. Survivors describe 14 burial trenches with 3,000 to 4,000 murdered victims in each one. Working in the area, which today is an open park, "was something very sensitive," Bauman says. "We had to ask permission from the museum and the Jewish community because we didn't want to disturb the burials."

Bauman was attempting to "distinguish areas of mass graves from background areas." A map of the burial trenches was available from Soviet excavations carried out in the 1960s, but their precise locations were unclear. "We know historically people would wander that field and see bone and ash," he says.

There were no coffins or caskets in the Battlefield for the geoscientists to target with electronic equipment. Tens of thousands of the bodies had been exhumed, their bones crushed and their ashes scattered by the Nazis. Remnants, such as bullets and casings, tin cups, knives, spoons, combs, wire frames for spectacles, and a rare passport with a photograph, had been found earlier. Postwar, a Soviet-era monument was constructed.

Bauman employed a process that identified phosphorus concentrations in the ground. The process was less familiar to him and he relied on email advice from archaeological phosphate expert Johanna Ullrich O'Keeffe. Phosphates tend to bind to receptors in the soil. The greater the clay component in the soil, the more receptor sites are available. Phosphate retention is lost in extremely sandy soils, but there was still leeway at Fort IX. Burials would deposit phosphates in organic form. Over time, these organic phosphates mineralize as they remain in the soil.

Although it had only been 78 years since the mass burials in the Battlefield, the geoscientists figured the phosphorus process would help locate them. Mineralization begins immediately after burial, and generally takes about 200 years, but the process of phosphorus release is accelerated by burning and crushing. That made it more likely for geoscientists to see a "phosphorus shadow" in the topsoil. Grass or plants will draw the phosphorus up from the soil column to shallower depths. "You can just sample down to 20 centimeters and capture the indications of higher phosphates," Bauman says. Indeed, nine of the 14 trenches corresponded to high levels of phosphorus, corroborating survivors' testimonies that the area was a graveyard of Nazi murder victims.

Holocaust survivors tell another harrowing story about Fort IX. In August, 1943, the Kaunas gestapo received *Sonderaktion* (special action) *1005* from Berlin.

JOSIE BAUMAN

Anticipating Nazi retreat from the Baltic states, the order was to eradicate the mass graves by January, 1944. Seventy-five prisoners at the fort were pressed to carry out the order. They included former Ghetto inmates and Red Army prisoners of war. Sixty-four prisoners became the "Burning Brigade." Mikhail Geltrunk, a survivor, testified in 1946, "We exhumed and burned 600 bodies a day. That was the quota fixed by the Germans. Two huge pyres with 300 bodies in each were burned every day. After the bodies had been burned the bones were crushed with metal tools and buried." After the ashes and crushed bones were buried, another survivor said, "the Hitlerites filled in the ditches, plowed up and sowed the field."

Science is the next frontier that will speak about these sites.

While the awful work was underway, the prisoners in the Burning Brigade were planning an escape. On Christmas Eve, 1943, with the lights out and the guards leaving for a night of revelry, the escape began. Lithuanians had built cement tunnels beneath the fort before the war. From their locked cells, the prisoners reached a tunnel with a locked door. They broke through the door and clambered through another tunnel to reach the inner yard of the prison. The escapees clambered up a wooden ladder placed in a wall and utilized a makeshift ladder to get over the barbed wire on top of the prison wall, across a moat, and into an open field. The daring escape was completed by Christmas morning.

While Fort IX holds several artefacts to commemorate the escape, details need to be filled in. The geoscientists know the direction the escapees fled, and this summer aim to track their escape using multispectral cameras mounted on drones. The green spectral band in images taken by the drone may correlate with vegetation stress. This may be due to buried construction material that has limited root growth. Unusually healthy vegetation due to a trench, which may be capturing more moisture and nutrients, would be indicated as well. The geoscientists want to find the hiding areas the escapees may have used in the nearby forest.

GEOSCIENTISTS HAVE another ambitious project planned for this summer—searching for a lost cache of information about Nazi crimes and Jewish heroes in Warsaw. Between 1940 and 1943, an organized underground operation, comprising dozens of contributors, collected thousands of documents: photographs, drawings, writings, journals, and tabulations, signed and dated. They put them into 2-foot-high metal milk cans and metal boxes, and buried them in the Warsaw Ghetto. Called the Ringelblum archives after historian Emanuel Ringelblum, the caches were buried in three different locations. In 1946, a survivor found the first of the milk cans. According to Freund, the archives were used as evidence in the Nuremberg trials. The second part was discovered in 1950. The archives were used in the trial of Adolf Eichmann in 1961. No one has found the third cache.

Today, Freund and the geoscientists are working with the Warsaw Ghetto Museum to find the third cache of the Ringelblum archives, which they expect is stored in a metal milk can. They know how deep the can is planted and where it was last seen. Uncovering the cache would be another chapter in the Holocaust story, and further testament to science helping get history right.

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Dreaming Is Like Taking LSD

A new theory explains that dreaming opens our minds to unexplored possibilities

BY ANTONIO ZADRA & ROBERT STICKGOLD

W**ITHOUT A DOUBT**, the biggest questions about dreaming are all variants on this question: Why do we dream? We began studying dreaming in the early 1990s and, between the two of us, have published over 200 scientific papers on sleep and dreams. Pulling together a variety of compelling neuroscientific ideas and state-of-the-art findings in the fields of sleep and dream research, we propose a new and innovative model of why we dream. We call this model NEXTUP. It proposes that our dreams allow us to explore the brain's neural network connections in order to understand possibilities. Think of it as similar to the true goal of education—not to cram facts into our brains, but rather to open us to the unexplored possibilities embodied within those facts, showing us the many ways they can be used and not just one specific way.

AGSANDREW / SHUTTERSTOCK

Dreaming is a form of sleep-dependent memory processing that extracts new knowledge from existing information through the discovery and strengthening of previously unexplored associations. In doing so, dreams rarely replay active concerns directly or offer concrete solutions to them. Rather, they identify and strengthen associations that in some way embody these concerns and that the brain calculates may be of use in resolving them or similar concerns, either now or in the future.

At the same time, dreaming creates narratives that unfold in our minds across time and allows us to experience the thoughts, sensations, and emotions engendered by those narratives. Dreaming, like waking consciousness, allows us to imagine sequences of events, to plan, to plot, to explore. Even when a problem doesn't inherently require the development of a narrative—for example, figuring out whether adding two odd numbers always produces an even number—we nonetheless create narratives to help us solve them. We "think out loud" about it, "run through it in our mind," and sometimes go through a series of "steps" as we solve it.

Typically, the brain starts with some new memory, encoded that day—maybe an important event, a discussion overheard at work, or something related to a personal concern—and searches for other, weakly associated memories. These can be from the same day, or they can be older memories from any time in the dreamer's past. The brain then combines the memories into a dream narrative that explores associations the brain would never normally consider. In doing so, NEXTUP searches for and strengthens the novel, creative, insightful, and useful associations discovered and displayed in our dreams.

Dreaming is a form of memory processing that extracts new knowledge from existing information.

One of us, Bob, measured the brain's preference for weak associations during REM sleep in a study published back in 1999.[1] He used a cognitive test called semantic priming, developed by James Neely at Yale 20 years earlier. It's a clever test. Participants sit in front of a computer screen as a series of words and non-words, such as "right" or "wronk," are flashed on it. Their task is simply to respond to each of them by pressing a key labeled "word" or one labeled "non-word." At the end, Bob calculated how fast and how accurate participants were when responding to the words and non-words. But that's not the whole story. Before each of these targets was displayed, another word was flashed on the screen for a quarter-second. Depending on the semantic relationship between this "prime" word and the target word (when it was a word), people responded more or less quickly.

Participants identify the word "wrong" faster when it's preceded by a strongly associated word like "right" than when it's preceded by a weakly related word like "thief." And they respond faster in both of these examples than when it's preceded by a completely unrelated word like "prune." How much faster someone responds is a measure of their semantic priming. When Bob tested participants during the day, he got exactly the results he expected—strong primes like right produced three times as much priming as weak primes like thief.

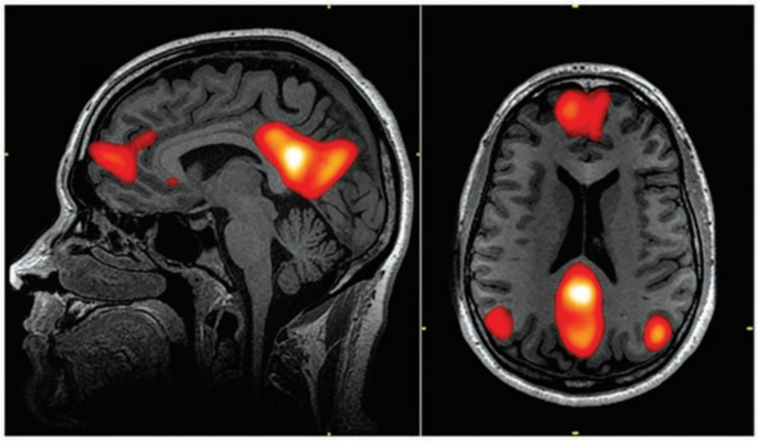
But what does it mean? Every time you see a word, your brain activates circuits that allow it to remember the sound and meaning of the word. But it also activates memories of related words. Not only does this activity enable you to understand the word better, but it also prepares the brain for what might be coming next. And the more strongly it activates the memory of a given related word, the faster and more reliably you will be able to identify that word when it does come next. That's exactly what we're measuring here. When you respond to wrong a lot faster after a strong prime like "right" (compared to an unrelated word like "prune"), it means your brain strongly activated the target word wrong in response to it. Bob's results suggested his participants' brains were activating strongly related words three times more effectively than they were weakly related words.

Bob was able to run this test very quickly; he could get participants through the entire test in just 2 to 3 minutes. This is much faster than the time required for the brain to become fully awake, and for its levels of neuromodulators like serotonin and noradrenaline to shift back to waking levels. By testing participants as soon as they woke up, he was able to ensure that their brains' neuromodulator levels were still close to where they had been before waking up. He tested them right after waking them from REM sleep in the middle of the night, and the results were better than he could have hoped for. Priming produced by strongly related words dropped by 90 percent, while that produced by weak primes increased more than twofold. When participants were awakened from REM sleep—and presumably while they were in REM sleep just a few minutes earlier—their brains were activating weakly related words eight times more effectively than strongly related words.

The dreaming brain is searching more widely than during wakefulness, digging for hidden treasures.

When our brains dream, this preference for weak associations helps explain why so many of our dreams lack any transparent connection to the dominant thoughts, feelings, and events of our day. Even when connections are obvious, the usefulness of a dream usually isn't. But this is exactly what NEXTUP predicts—weakly associated networks are being explored to understand possibilities.

The brain is searching more widely than during wakefulness, going through less obvious associations, and digging for hidden treasures in places it would never consider while awake. In the glare of the day—when our brains are dealing primarily with new incoming sensations and the balance of neurotransmitters in our brain is optimized for processing the here and now—the usefulness, or "rightness," of these newly found associations might be incomprehensible. But that's fine. We don't need to understand why our brain chose these associations. We don't need to know whether the associations used to construct a given dream were useful. We don't even need to remember the dream. All the important work was done while we slept. Associations were discovered, explored, and evaluated while we dreamed, and if our brain calculated that some of them were indeed novel, creative, and potentially useful to us, then it strengthened them and filed them away for later use.



DREAM HOME The brain's default mode network, pictured above, monitors the environment, watching out for any danger, and helps us recall past events and imagine future ones—mental functions associated with mind-wandering. Much of the DMN is also activated during REM sleep, suggesting the term "daydreaming" may be more appropriate than we thought.

JOHN GRANER, NEUROIMAGING DEPARTMENT, NATIONAL INTREPID CENTER OF EXCELLENCE, WALTER REED NATIONAL MILITARY MEDICAL CENTER

MANY OF OUR DREAMS may feel strange and meaningless, but a surprising number of them seem to engender in us a strong sense of their importance. Why does this happen? If the function of dreaming doesn't require our remembering them, and if we remember so few of them in any case, why should they feel so meaningful when we do? (Indeed, this idea of meaningful dreams is seen across all cultures and across thousands of years.)

We know that the brain is specifically searching for weak associations. This means it is exploring associations that, under normal circumstances, it would reject as somewhere between uninteresting and just plain ridiculous. When we're dreaming, the brain must shift its bias toward scoring associations as potentially valuable when it normally wouldn't. It needs to give itself a little push if it's going to decide that any of the weak associations incorporated into its dream narratives are meaningful and useful.

It's a little like the '60s, when people were dropping acid and having profound "acid insights" along the lines of, "When you flush the toilet, everything goes down!" They would tell you this, wide-eyed in awe at their amazing insight, then get a bit sheepish and say, "It meant more than that; it really explained everything."

In fact, the feeling that dreams have meaning is not just a little like the '60s. It's likely identical. Pharmacologically, lysergic acid diethylamide (LSD) works by activating the serotonin receptors, including serotonin 1A receptors, which in turn can block the release of serotonin in parts of the brain. All the weirdness of LSD—the hallucinations and acid insights and everything else—may be a direct consequence of this biochemical blockade of serotonin release.

This obviously isn't the normal state of affairs in the brain. But there is one time every day when serotonin release is completely blocked, and that's during REM sleep. We dream in both REM and nonREM sleep, but the most bizarre, emotional, and unlikely dreams—and arguably those that seem most meaningful to us—occur in REM sleep. The reduction in serotonin levels during nonREM sleep (relative to wakefulness) and the complete cessation of its release during REM sleep may serve the important role of shifting the brain's bias toward assigning more value than it otherwise would to those weak associations activated during dream construction. This chemical action may be the grease that enables these potentially useful new associations to slide into our repertoire of valuable insights.

This is just one of the differences in the chemical neuromodulators being released in the brain during sleep. These chemicals control how nerve cells communicate with one another; at the whole brain level, they essentially act to switch the software running the brain. You just learned that serotonin can affect a dreaming person's sense of how significant a weak association is. When serotonin release is blocked during REM sleep, it leads to an increased sense of wonder and importance for whatever weak association happens to be found. Serotonin release isn't fully blocked during nonREM sleep, so this bias toward favoring weak associations will be diminished. But that's just fine, because the brain isn't looking for weak associations during nonREM sleep.

Bob's semantic priming experiment showed that our normal preference for strong associations is replaced by one for weak associations during REM sleep. This effect is probably due to a second neuromodulator, noradrenaline, that's also being shut off during REM. Noradrenaline is the brain's version of adrenaline; one of its many functions is to focus our attention on what's right in front of us. You've probably noticed that when you're under pressure and your adrenaline levels skyrocket, you don't want to think about a bunch of unlikely alternatives to what you are trying to do. You're so focused, almost nothing can change your course. The disappearance of noradrenaline from the brain during REM sleep makes it easy for your brain to wander among its weak associations.

IN RECENT YEARS, thanks to brain imaging, scientists have discovered the brain's preference for weak associations during wakefulness, specifically to dreaming's cousins, daydreaming and mind-wandering. Scientists had long assumed that the activity pattern seen during quiet rest reflected the activity of a brain not doing anything. In retrospect, this was obviously a foolish assumption. Our brains are always thinking about something. The brain areas that turn off when we start to carry out a mental task are the regions that do whatever the brain does when we're "not doing anything." Together these regions make up the default mode network (DMN), whose discovery has helped us appreciate just how true it is that the brain never rests.

When we look at the brain regions that make up the DMN, we find a sub-network that monitors the environment for important changes, watching out for any danger. Keeping us safe is probably one function of the DMN. But we also find a sub-network that helps us recall past events and imagine future ones, another that helps us navigate through space, and yet another that helps us interpret the words and actions of others. And these are the mental functions associated with mind-wandering. Much of mind wandering involves hashing over the events of the day or anticipating and planning future events. Indeed, such planning has been proposed as a function of mind-wandering.[2] So it's perhaps not surprising that mind-wandering is associated with increased activity in the DMN.[3] This appears to be a second function of the DMN.

When serotonin release is blocked during REM sleep, it leads to an increased sense of wonder and importance.

The DMN is not a static structure, however. It changes based on what you've been doing earlier. Bob and his colleague Dara Manoach looked at how activity in the DMN changed after doing one of Bob's favorite tasks: his finger-tapping task, which involves learning to type the sequence 4–1–3–2–4 as quickly and accurately as possible.[4] Young participants get a lot better in just a couple of minutes of practice, but then they plateau. A period of rest in the same day doesn't make them any faster, but if they get a night of sleep and then try again, they become 15 to 20 percent faster. It's another example of sleep-dependent memory evolution.

When Bob and Dara had participants learn the task while having their brains scanned, with periods of quiet rest before and after the training, they found that brain regions involved in performing the task were talking to each other more during the quiet rest after training than during the quiet rest before training. The DMN, which is normally measured during such periods of quiet rest, was altered by performing the task. And more important, the more the DMN was altered, the more improvement participants showed the next day. It was as if this new DMN activity was telling the brain what to work on once it fell asleep.

Indeed, much of the DMN is also activated during REM sleep, suggesting that the term daydreaming may be more appropriate than we thought. William Domhoff and his colleague Kieran Fox have gone so far as to suggest that dreaming, or at least REM sleep dreaming, constitutes a brain state of "enhanced mind wandering."[5] More recently, Domhoff has proposed that the neural substrate of dreaming lies within the DMN.[6]

When you put it all together, you get an exciting extension of our NEXTUP model. Whenever the waking brain doesn't have to focus on some specific task, it activates the default mode network, identifies ongoing, incomplete mental processes—those needing further attention—and tries to imagine ways to complete them. Sometimes it completes the process shortly after the problem arises, making decisions without our ever realizing it. But at other times it sets the problem aside after tagging it for later sleep-dependent processing, either within or without dreaming. Several dream theories have suggested something like this—that dreaming helps us address areas of concern in our lives. The DMN might provide the mechanism for identifying these concerns, thereby determining how NEXTUP, our Network Exploration to Understand Possibilities, works.

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We Crush, Poison, and Destroy Insects at Our Own Peril

Insects are escape artists. Now they face a threat more pernicious than predation.

BY JOHN HAINZE

THIS PAST SUMMER, my wife and I ventured to an area near Mount Adams in southwestern Washington state to census bumblebees. We camped there over the weekend as we took part in the Pacific Northwest Bumblebee Atlas survey. Scientists want to fill gaps in their knowledge about the bees. Learning about the relative number of different species, and their floral resources over a broad area, provides invaluable information, particularly when some species are in decline. I was helping to determine where conservation efforts may be needed. Survey participants choose a territory where they capture and photograph bumblebees on two occasions. I still marvel at the variety in the photos we took—bees with coloration incorporating rusty bands of hair, black stubby hairs, white patches, orange bands, and a brilliant, lemon-yellow covering of long hairs. Bumblebees are really quite beautiful when observed more closely.

KRIACHKO OLEKSII / SHUTTERSTOCK

It's not all honey and butterflies in our relationship with insects.

There is some risk involved, of course. Bumblebees have a painful sting and, unlike the honeybee, with its barbed stinger, the sharp, smooth bumblebee stinger can sting multiple times. Insect stings may serve two purposes. The first is to incapacitate prey. The second is to ward off predators. Bumblebees feed solely on pollen and flower nectar. So they would not sting to subdue prey. A bumblebee nest full of honey and nearly immobile larvae, though, is highly attractive to predators. The bumblebee sting is a weapon used for defense—a mechanism to escape predation from animals that may be 50,000 to 100,000 times their size.[1] And judging by the way most people respond, it works pretty well. The sting of the honeybee has been used as a reference point by sting pain connoisseur, Justin Schmidt. He rates the bumblebee and honeybee stings as a pedestrian 2 on his scale of 1-4.[2] But that's a sufficient wallop for people to keep their distance from these bees—and that's the way the bees like it.

The unparalleled success of insects as a group of organisms results from their ability to escape existential threats. They're escape artists. They've evolved multiple means of eluding the larger animals that endanger them—by stinging, biting, flying, jumping, running, startling, hiding in crevices, and using camouflage as well as chemical defenses. Yet these masters at evading far larger animals face a threat more pernicious than predation today. The resulting decline in the number of insects and in the number of insect species is increasingly well documented. Why should this be alarming? Insects play significant roles as food or in the growth of food for many organisms, including human beings. Insects are also recyclers, decomposing plant matter and animal dung and contributing to the organic content of soils.

It's been said that if human beings disappeared, we would not be missed. Insects and other organisms would thrive. Yet we and many other animals would not survive were insects to disappear. The plight of the island marble butterfly (*Euchloe ausonides insulanus*) and the western bumblebee (*Bombus occidentalis*) exemplify the multiple stressors on insect survival in the Anthropocene, the proposed name for a new epoch in which human-generated change outstrips the effect of natural forces on the Earth. What responsibilities, if any, do we bear toward these insects? And what can each of us do to stem the tide of global insect decline?

In my recent book, *Nature Underfoot*, I argue that we crush, poison, and destroy insects and their habitat at our own peril. Yet reasons for acting to prevent insect decline run much deeper than self-interest. Humans cause habitat loss, produce pesticides, and import non-native species. We bear, according to certain strands of

FIGHT OF THE BUMBLEBEE A 2017 global study found that one-third of assessed bumblebee species were in decline. The U.S. is studying whether to place the western bumblebee on the endangered species list.

STEPHEN AUSMUS, USDA ARS / WIKIMEDIA

philosophical and religious thought, responsibility for the catastrophic losses insects experience today. Some say that insects have moral value since they strive to achieve their ends, just as we and other animals do. Others argue that insects have moral value as a part of God's creation. Scientists point to the value of insects in global ecosystems, or the value implied by tens or hundreds of thousands of years involved in the evolution of an insect species.

THE INSECT APOCALYPSE has captured headlines, but the situation is more nuanced than that. Scientists find an increase in the overall numbers of arthropods in the Arctic, but a decline in diversity. Certain habitats in the Arctic are also affected more than others.[3] In Puerto Rico, insect declines initially attributed to climate change may have resulted instead from hurricanes.[4] Some insect species have even increased in numbers—mainly those that are tolerant of human activities or that benefit from associating with humans or from climate change.

Despite that, the general trend is negative as climate change, habitat destruction (in the form of deforestation, urbanization, and intensification of agriculture), and pesticides take their toll. These forces are overtaking the insects. They are coming so quickly that even these spectacularly successful evolutionary improvisers do not have time to escape. It's often difficult for scientists to identify a single contributing factor. A new paper, introducing a special issue on the plight of insects, published in the *Proceedings of the National Academy of Sciences*, referred to the decline of these tiny creatures as "death by a thousand cuts."[5]

There is a paucity of long-term records for insect populations. The best historical records are for moths and butterflies in Europe and North America. The story of the island marble butterfly, a grassland species, illustrates the myriad forces arrayed against insects. It was declared endangered in the United States in May of 2020. It is charmingly small—mostly white on the tops of the wings and mottled green, yellow, and white on the undersides. Perhaps its colorful camouflage is a way of escaping predation. This little butterfly was thought to be extinct since 1908, when it was last collected on Gabriola Island, British Columbia. Quite by accident 90 years later, while conducting a survey of butterflies in Puget Sound prairie habitats, a Washington state biologist, John Fleckenstein, collected two of these butterflies on San Juan Island. Neither Fleckenstein, nor his colleague, Ann Potter, could identify the butterflies as they reviewed his collection. So, Potter took the butterflies to a butterfly conference in Corvallis, Oregon, where experts were ecstatic to see the butterfly once thought extinct![6]

The Lazarus-like return of the island marble butterfly is remarkable, but the pressures that endanger it remain. The prairie habitats where the butterfly is found have been farmed, used for pasture, and developed for housing, destroying much of its original habitat. The butterfly caterpillars feed and develop

We and many animals wouldn't survive if insects disappeared.

on plants in the mustard family. The native mustard, Menzies' pepperweed (*Lepidium virginicum* var. *menziesii*), that must have originally supported the butterfly, is often found surrounding lagoons on San Juan Island. These plants and the island marble butterfly are damaged by winter storm surges, which will become more serious as climate change causes sea levels to rise. Fortunately, the butterfly has adapted to feeding on two non-native plants, field mustard (*Brassica rapa*) and tumble mustard (*Sisymbrium altissimum*) that grow elsewhere on the island.

Other invasive species have had a more deleterious effect on the island marble butterfly. The brown garden snail (*Cornu aspersum*), brought from Europe to the west coast as a source of escargot, competes with the island marble butterfly in consuming field mustard and tumble mustard. The European rabbit (*Oryctolagus cuniculus*) develops large populations in the San Juan Islands and also feeds on butterfly host plants. Deer, though native in the San Juans, are destructive of prairie habitat. Deer numbers are very high there because their predators, such as wolves, cougars, and bears, were eliminated by European settlers. Deer not only destroy island marble butterfly habitat, but they may ingest eggs and caterpillars in the process. Island marble butterflies also suffer from predation by native spiders and by a European paper wasp (*Polistes dominula*).[7]

A vigorous and widely distributed population of butterflies could withstand the pressure of predation, but it poses a significant risk for the tiny, localized population of island marble butterflies. Death by a thousand cuts. Habitat destruction, loss of food plants, invasive species, climate change, and predation are primarily human-driven problems. Fortunately, what is believed to be the last island marble butterfly population falls within the boundaries of the San Juan National Historic Park. Here, the park service is actively rearing and releasing butterflies and making a significant effort to preserve their habitat. The island marble butterfly is in a fragile state but hopefully its new endangered status will yield another amazing recovery.

Bumblebees experience similar problems, and the citizen-science survey I described endeavored to generate information about wild bumblebee status—where they occur and what they feed on. They can be found from just east of the Rocky Mountains to the west coast and north from Alaska to Saskatchewan. The tip of the western bumblebee abdomen can be whitish or rusty, yellow hairs may be present or absent above that, and all of these bumblebees have yellow hairs at the front of their thorax behind the head. Bumblebees are important pollinators and, for certain plants, such as tomatoes and blueberries, are better pollinators than honeybees. This led to the domestication of bumblebees for pollination in agriculture, particularly in greenhouses.

In 1992, the U.S. Animal and Plant Health Inspection Service allowed the importation of western bumblebees raised in Europe into the U.S. In 1997, production facilities in California were devastated by a fungal parasite, *Nosema bombi*, possibly originating in Europe. At the same time, high levels of *N. bombi* were found in wild western bumblebee populations, appearing to be related to their significant decline. The coincidental timing of the disease among domestic and wild populations and limited analysis of the parasites indicated that the domestically reared bees infected the wild populations.[8] If so, it's another example of how human manipulation of nature may have unforeseen consequences (though some would say the problem was not unforeseen). The commercial production of western bumblebees became financially impractical in the early 2000s.

We had hoped to see the western bumblebee in our sampling, because its numbers have dropped precipitously in our area. The western bumblebee was once widely distributed and one of the more common bumblebees found in western North America. More recently, since 1998, western bumblebees have become

EDGE OF EXTINCTION The Lazarus-like return of the island marble butterfly is remarkable, but the pressures that endanger its prairie habitats remain.

PUBLIC DOMAIN

more difficult to find, particularly west of the Cascade mountains from California to British Columbia. The U.S. Fish and Wildlife Service is currently studying whether to place the western bumblebee on the endangered species list, with a decision planned by 2023.

The western bumblebee is not alone in its misfortune. A 2017 global study found that one-third of the bumblebee species they assessed were in decline.[9] This habitat loss is driven by agriculture and urbanization, pesticides, climate change, and competition from non-native species. The presence of the bees across their range, based on the modeling of existing data, has been reduced by 93 percent between 1997 and 2018.[10] Scientists will continue to assess the viability of the species as the Fish and Wildlife Service works to determine whether it requires the protection of the Endangered Species Act. Again, death by a thousand cuts is an apt description of the situation facing the western bumblebee. If the *N. bombi* doesn't get you, habitat loss will.

OF COURSE, IT'S NOT ALL honey and butterflies in our relationship with insects. There are occasions when it's us or them. Insecticide-treated bed nets and spraying long-lasting insecticides on indoor surfaces are some of the best ways to prevent the spread of malaria, which can be debilitating or fatal for many. Destroying the habitat of *Anopheles* mosquitoes in the southern U.S. helped eliminate malaria there.

But if we agree that we have a responsibility to act to conserve insects, then what can individuals do to aid and abet their escape from human-caused difficulties? There is much we can do in our own yards by constructing a more diverse habitat using native plant species. It is possible to encourage certain species by planting their food plants. There is a program underway in the U.S. to get property owners to plant milkweed (*Asclepias syriaca*) to support monarch butterflies (*Danaus plexippus*). Some residents on San Juan Island are also planting the mustard species that are important to the survival of the island marble butterfly. These

To conserve insects, there is much we can do in our own yards.

contributions will help offset some of the degradation of insect habitat. Limiting pesticide use, including insecticides, fungicides, and herbicides, would help. I estimate, based on U.S. Environmental Protection Agency data, that around 70 percent of U.S. households use chemical pesticides of one kind or another. We can also limit the use of outside lighting. It makes it difficult for nocturnal flying insects to orient and may kill those that are attracted to the lights.

It would help insects to have more advocates. Speaking up for the conservation of endangered insects is important. Supporting candidates that promise to follow the science and take action against climate change would be another positive step. And, finally, consider joining a citizen-science initiative that provides needed information on insects, not unlike the bumblebee survey I enjoyed. I promise that you'll be amply rewarded as you explore another, smaller dimension of the natural world.

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Why a Universal Society Is Unattainable

Our minds evolved in an Us-vs-Them universe of our own making

BY MARK W. MOFFETT

ARTHIMEDES / SHUTTERSTOCK

ON JAN. 1, 2021, five long years after the vote for what's become known as Brexit, and numerous marches before and after that national decision, some of which attracted more than 100,000 impassioned participants, Great Britain formally severed its nearly half century-long ties with the European Union. The decision, as columnist Owen Jones described it in *The Guardian*, was to foment "an all-out culture war."

In the 2016 vote, the majority of British people stubbornly chose for their country to be on its own and not part of a more encompassing group of societies. The vote appeared to run against the broader trend of European nations loosening their boundaries in acknowledgement of an identity that outweighs, or erases, the importance of the societies themselves. With the number of societies in general declining century after century,[1] we might take seriously the assertion that the internationalization of culture (think *Star Wars*, tequila, Mercedes-Benz) and connections (with Twitter linking people from Aa, Estonia, to Zu, Afghanistan) are a harbinger of a Berlin Wall-type border collapse, making, as the British sociologist Morris Ginsberg once put it, "The unification of mankind [is] one of the clearest trends in human history."[2]

Whatever the ultimate relationship of Great Britain and Europe may be, the current breakup underscores how deeply national identity runs through human psychology. A review of both the psychology literature and anthropological research on societies ranging from the ethnolinguistic groups of hunter-gatherers to tribes, chiefdoms, and states (less formally, "nations"),[3] reveal that a universal society is unattainable. Populations across the globe today may devour Starbucks, KFC, and Coca-Cola. They may enjoy Italian opera, French couture, and Persian carpets. But no matter how many exotic influences each absorbs or what foreign connections they make, nations don't just fade away. They retain their citizens' fierce devotion. Societies have always traded, gifted, or taken what they want from the outer world to claim as their own, and grown all the stronger for doing so. While the erasure of borders may be laudable, nothing we know about the workings of the human mind suggests it is a realistic vision.

The European Union offers no grand foundation story, no venerable symbols or traditions.

THROUGHOUT HISTORY, humankind has successfully erected umbrella organizations composed of multiple societies. That such groups fail to supersede bonds to the societies themselves is demonstrated by the most binding association of societies in the anthropological record. In northwest Amazonia reside 20 or so tribes, or language groups, known collectively as the Tukanoans. Each has its own language or dialect, some similar, some mutually unintelligible. The tribes are tied economically, each a specialist on goods it exchanges with the others. Cross-connecting them are what amount to obligatory trade relations of a novel sort: Marriage within a tribe is improper. "Those who speak the same language with us are our brothers, and we do not marry our sisters," the people say. Thus a bride marries into another tribe, where she learns the local tongue.

One explanation for this arrangement is that it reduces inbreeding in small societies, an incestuous act to which *Homo sapiens* has an innate abhorrence. We see this in many nonhumans as well, such as in chimpanzees, where females avoid mating with kin by likewise transferring between communities. The psychological aversion to marrying a sibling presents a far greater problem for the Tukanoans, whose numbers have been miniscule at times in the past, than for the massive countries of today. Perhaps this fear overpowered any trepidation those people have about firmly bonding their societies. The compulsory spousal exchanges have created some of the tightest alliances ever recorded, currently totaling about 30,000 Amazonian souls. Yet for all that, Tukanoan tribes remain clear and separate, each confined to specific areas.[4]

A failure of alliances to supersede people's affiliation to their society holds true universally. Intergovernmental organizations like the European Union and the United Nations don't earn our primary emotional commitment because they lack ingredients that make them real for the members. The EU may be the most ambitious attempt at societal integration conceived, yet few members see the EU as an entity worthy of their loyalty the way they do their countries, and for several reasons.

First off, the EU's borders are indefinite—indeed, are subject to revision as states enter or go. Additionally, its members have a history of conflict dating from the Middle Ages, and a split already exists from east to west among communist and capitalist cultures. To top all that off, the EU offers no grand foundation story, no venerable symbols or traditions, and there's little sense anyone would fight and die for Europe as they might for their nation.[5] That makes the EU a political coalition much like the Iroquois Confederacy once was for six American Indian tribes, or the league of states formed within what is now China during the sixth century B.C.

If a mass hypnotist caused us to forget our differences, we would scramble to invent new ones.

The strength of such associations wax or wane given their value at the moment. As with our personal relationships, friends can become enemies who turn into friends again, something that's been shown for the ever-shifting relationships among many American Indian tribes.[6] Each country in the EU handles passports and other issues relating to its citizens' identity and remains the focus of their self-worth, an outlook that makes its membership secondary and disposable. Analysis of the 2016 Brexit vote shows that those who most strongly think of themselves as English went against staying with the EU. Voters saw what was intended foremost to be an economic and peacekeeping tool as a threat to their identity. The fact is the consequences of Brexit will be mostly commercial, setting into action a myriad of obstacles to trade.

Ironically, Britain's relations with the EU unraveled when its self-identity was under stress, with Northern Ireland and Scotland increasingly likely opting to secede from the United Kingdom, a fracture along ancient cultural lines that's the norm for modern societies.[7] Meanwhile, the loss of Britain has invigorated the ties of the member nations to the EU, along the lines of what one sees when a group of people pull together in the face of adversity—but that doesn't mean the divisions within the EU will disappear.

Financial and security issues hold the EU together. The same can be said for Switzerland, a country subject to perennial scrutiny because, as the four languages and complex territoriality of its people attest, its nationhood rests on a detailed social and political alliance between 26 local communities, or cantons. These self-governing settlements act in many respects as miniature nations nestled in a mountain landscape that enhances each one's physical separation and autonomy.[8] "Each Canton has its own history, constitution and flag, and some even have an anthem," political scientist Antoine Chollet reports, such that Swiss "citizenship refers to one who can vote and nothing more."[9] Formation of the Swiss confederation required rewriting accounts of the past to maintain a sense of equality between the cantons, allowing them to survive over the centuries when they were forced to negotiate their interests with far larger and more powerful neighboring countries.

The EU and Switzerland are regional entities kept intact by perceived needs to counter hazards from outsiders, a motivating factor that gives both a reasonable chance of success. An absolutely global union would have

TOWN MEETING
Chimpanzees cling to members of their own societies, avoiding those they don't recognize, a trait humans seem to have inherited. However, we're not like our prehuman forbearers. We can learn to appreciate differences.

no such motivation, making it far more precarious. One possible means of attaining that unity might be to shift people's perception of who's an outsider. It was a point Ronald Reagan liked to make. "I occasionally think how quickly our differences worldwide would vanish if we were facing an alien threat from outside this world," he remarked in an address to the UN. Indeed, science-fiction tales like *The War of the Worlds* depict humankind acting as one against a common enemy.

Yet even then our societies would endure the space aliens. The arrival of Martians wouldn't make nations irrelevant any more than Europeans arriving in Australia caused the Aborigines to drop what had been several hundred clear-cut tribal groups (actually, many Aborigines first guessed that the Europeans were otherworldly, i.e., ghosts). That would be so regardless of how much the aliens shattered the beliefs people held about their own societies, whose beloved differences would look trivial by comparison to those with the Little Green Men. Cosmopolitanism, the conviction that the diverse people of our planet will come to feel a primary connection to the human race (the term means "citizen of the cosmos"),[10] is a pipe dream.

BUT WHAT MIGHT HAPPEN if people could forgo those traits that "mark" their identities or somehow put aside the drive to categorize each other by means of such labels—to separate us from them based on language, clothing, gestures, or religious beliefs? In such a world the only reliable differences we would perceive would be between individuals—not between groups. One supposes that under such circumstances our nations would disintegrate entirely, but it's hard to predict what would rise in their stead. Maybe our affiliations would coalesce around local neighborhoods or around those who we know best, with the global population splintering into millions of micro-nations. We might foresee a return to the societies of our prehuman forebears, when, like chimpanzees and most other vertebrates, every individual literally had to remember everybody else in their society.

PATRICK ROLANDS / SHUTTERSTOCK

Or, by discarding our differences, or our penchant for making judgments about the differences, could we achieve the opposite result, doing away with societies entirely? Would the beehive of networks built up through international travel and Facebook friendships interlink us so indiscriminately that we would actually secure that elusive panhuman unity that some aspire to, encompassing every man, woman, and child?

The human reliance on particular traits, or "markers," to identify with our societies, ethnicities, and other groups may trace back far into the human past, but what comes naturally isn't always desirable. Fortunately, our intelligence gives us some prospect of breaking free from our biology and history. When changes concern the matter of how we mark off our identities, though, any alteration would be extremely arduous and require more than education. While casting off ethnic and societal markers may sound good at first blush, the move would undoubtedly mean the loss of much of what humans cherish. Our markers are two-edged swords, causing us to discount those who differ from us, yet at the same time imparting an *esprit de corps* with complete strangers who fit our expectations, as when we take delight in conversing with a fellow American when traveling overseas.

To abandon our differences would strike against timeless yearnings. People care about their memberships and few would want to give them up. Nor could we simply dispose of them. Research in psychology shows that our responses to the most entrenched of our social groups, and the characteristics that define them, take place faster than the blink of an eye, and are involuntary.[11] No doubt if a mass hypnotist caused us to forget our current differences, we would scramble to discover or invent new differences to hold dear.

The only way to retool this human attribute would be for a surgeon from the far future with near-miraculous understanding of the nervous system to ablate portions of the brain. The result of this science-fictional adjustment would be a creature we wouldn't recognize as ourselves. I'm unsure how one could measure whether such people were any happier than we are today, but surely, they would no longer be us.

As for humans, with the minds we have now, the question of whether an identification with humankind is enough or societies need to exist really boils down to whether people must be part of a society for their emotional health and viability. "A man must have a nationality as he must have a nose and two ears," wrote Ernest Gellner, a prominent thinker on nationalism. Gellner—who went on to argue, mistakenly, that the human need to be part of a nation is nothing more than a contrivance of modern times—never fathomed how right his statement was.[12] The mind evolved in an Us-vs-Them universe of our own making. The societies coming out of this psychological firmament have always been points of reference that give people a secure sense of meaning and validation.

To say a person has no country then calls to mind dysfunction, trauma, or tragedy. With no such specific group identity, humans feel marginalized,

rootless, adrift: a dangerous condition. A case in point is the homelessness felt by immigrants who have lost connections to their native land only to face the sting of rejection by their adopted country.[13] Social marginalization has been a motivator stronger than religious fanaticism, explaining why many terrorists originally took to extremism only after being excluded from the cultural mainstream. For the socially dispossessed, radical views fill a void. Organized crime groups likewise commandeer some of the properties that give a society its vitality by providing social pariahs with common goals and a sense of pride and belonging.

All evidence points to societies being a human universal. Our ancestors evolved, by simple steps, from having societies where everyone knew all the other members to societies set apart by signals marking our identities.[14] The dividing lines of society memberships would have made it through this transition unaltered. What that means is there never was an original, "authentic" human society, never a time when all people lived in an open network of social relations that spread beyond the horizon line. Being in a society (indeed, in multiple societies) is a more indispensable and ancient quality of our species than faith or matrimony, having been the way of things from before we were human.

As with our personal relationships, friends can become enemies who turn into friends again.

To be sure, the number of societies has gradually declined over the long course of history, but far from being the result of group identities fading off into peaceful mergers, it's largely been the outcome of wars and domination.[15] The societies that have arisen after these consolidations still remain distinct from each other despite the diversity of their populations.

Given the contrasting, in fact ever-changing, identities and worldviews of those societies, one laudable aim of cosmopolitan thinkers and many others, to achieve a mutual respect for the rights and needs of varied cultures, will always be an onerous, and shifting, target. Yet recognizing the challenges will not only help us make sense of today's fractious world, but also guide us in surmounting such contentious issues as immigration and, in what are the first truly global crises we all face together, environmental loss, species extinction, and climate change.

Few facets of life match a society in striking passion in the human heart so long as other societies exist to compare with our own. Societies, and the differences that set us apart, are here to stay, signifying the boundaries between people in our minds, and setting the borders between us physically, across the earth's surface. Yet we can still aim for a more peaceful and just world. It begins with appreciating our differences.

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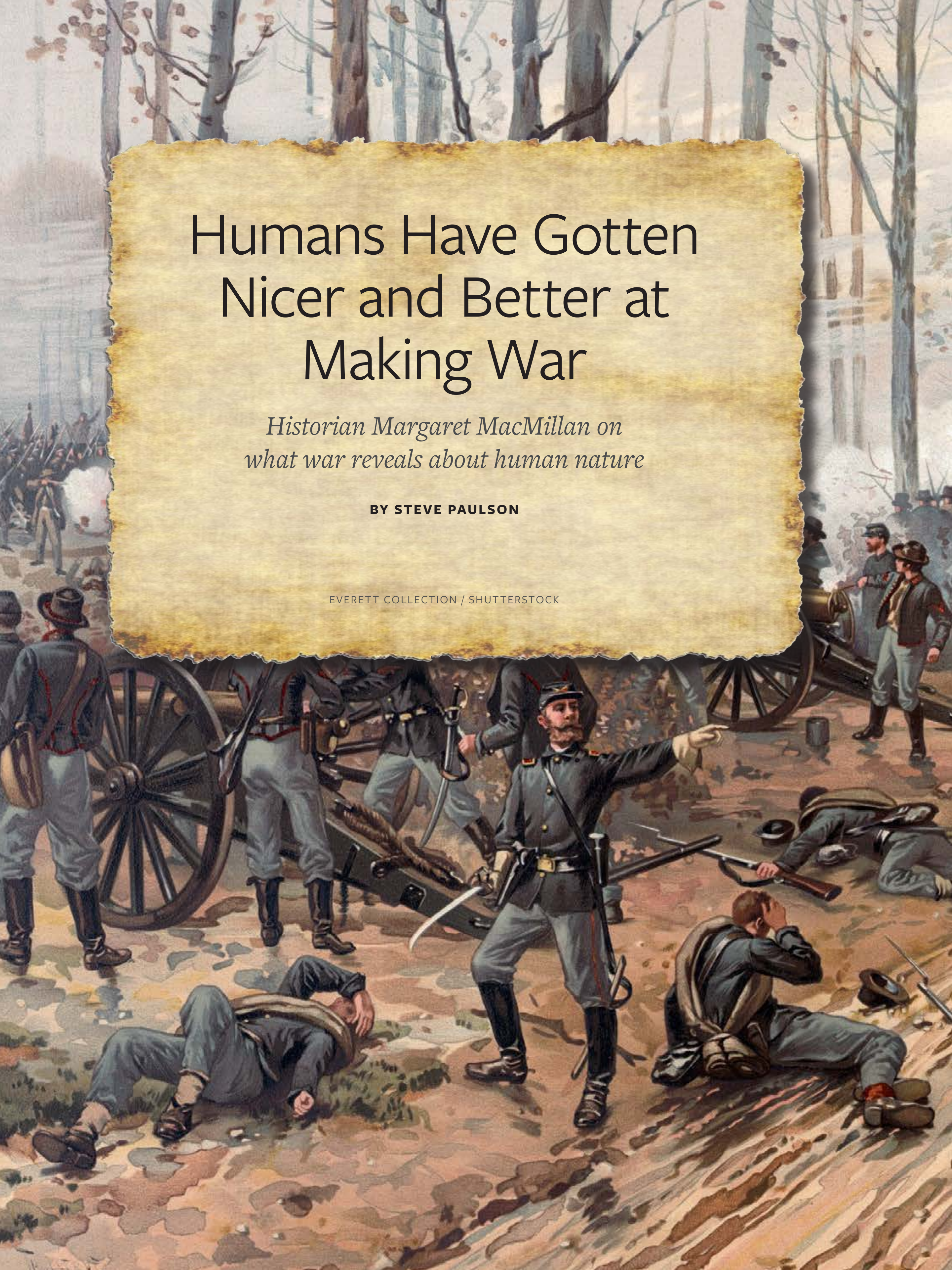
Humans Have Gotten Nicer and Better at Making War

Historian Margaret MacMillan on what war reveals about human nature

BY STEVE PAULSON



EVERETT COLLECTION / SHUTTERSTOCK

IN 1991 TWO HIKERS in the Italian Alps stumbled on a mummified body buried in the ice. The Iceman, it turned out, died more than 5,000 years ago. At first, archeologists assumed he'd fallen in a snowstorm and frozen to death. Then they discovered various cuts and bruises on his body and an arrowhead embedded in his shoulder. They also found traces of blood on the stone knife he was carrying. Most likely, he died fighting.

Canadian historian Margaret MacMillan regards the Iceman story as emblematic of our violent nature. Humans are a quarrelsome lot with a special talent for waging war. In her book *War: How Conflict Shaped Us*, she argues that warfare is so deeply embedded in human history that we barely recognize its ripple effects. Some are obvious, like the rise and fall of nations, but others can be surprising. For all that we cherish peace, war has also galvanized social and political change, sometimes for the better. It's also sparked scientific advances.

MacMillan is the author of several highly regarded histories of war and peace. She also has a personal interest in this subject. Her father and both her grandfathers served in wars, and her great-grandfather was David Lloyd George, Britain's prime minister during World War I. But she says her family history isn't that unusual. "I'm in my 70s and most of us have had family members who were in the First World War or the Second World War or knew someone who was in either war," she told me.

MacMillan synthesizes a vast body of literature about war, from battlefield accounts to theories of war, and she shows how new technologies and weaponry have repeatedly changed the course of history. As I discovered during our conversation, she's especially interested in the question she poses at the beginning of her book: "Does war bring out the bestial side of human nature or the best?"

WAR HISTORIAN Margaret MacMillan has a personal interest in her subject. Her father and both her grandfathers served in wars, and her great-grandfather was David Lloyd George, Britain's prime minister during World War I.

ANDER MCINTYRE

Do you think human beings are inherently violent?

I come down on the side that we're not inherently violent but we may have violent tendencies that evolution has left us. When we're afraid, we have a tendency to lash out, but I don't think that means we are necessarily violent. We often see examples of altruism and people living together. What is more important is why people fight—and I'm thinking of war, not just random one-on-one fighting. People fight wars because of organization, ideas, and cultural values. The more organized we are, unfortunately, the better we seem to get at fighting. War is very organized. It's not the brawl you get outside a bar or the random violence you might get when someone feels frightened.

Steven Pinker says human beings are getting less violent, especially since the Enlightenment. What do you think of his argument?
It's a very interesting argument, which he makes with great evidence and subtlety. We no longer have prize-fights where people batter each other to death. We no longer have public executions. And in most developed societies and many less developed societies, the homicide rates are way down. Your own country, the United States, is something of an outlier there. I think his argument that we are becoming more peaceful in domestic societies is right. But I don't think that's war. War is something different.

There's a very interesting counterargument by Richard Wrangham called "the goodness paradox." He argues that we have, in fact, become nicer and less violent as individuals. We may have domesticated ourselves by our choice of mates and by breeding out those who are most violent, or killing those who are most violent among us, like the way wolves have been domesticated into friendly dogs who sit on your lap. We may have become nicer as individuals, but we've also become better at organizing and using purposive violence. That's the paradox. We've gotten better at making war even as we've become nicer people.

Isn't waging war actually uncommon in the animal kingdom?
Well, our nearest cousins, the chimpanzees, do seem to wage war. Chimpanzees will stake out their own territory and male chimpanzees will go out in bands to patrol that territory. If an unfortunate chimpanzee from another band stumbles into that territory, the chimpanzees will gang up and kill the intruder. But our other close cousins in the animal kingdom, the bonobo, do live in harmony and peace and don't react with violence to outside bonobos coming in. It may be because chimpanzees have natural predators and bonobos, for geographical reasons, don't.

Nationalism can be the same as religion. You will die for something bigger than yourself.

It's worth pointing out that bonobos are matriarchal, whereas chimpanzees are dominated by the big males.
And that leads to a very interesting speculation. Are men more likely to fight? Are they naturally more belligerent and are women natural peacemakers? I think not. Certainly the great majority of societies through history have been patriarchal. But when you get women in charge, they don't seem to be any less warlike than men. Think of Catherine the Great or Maria Theresa or Margaret Thatcher. All these women were quite capable of taking their countries to war.

If waging war is a natural tendency, perhaps in our DNA, what does that reveal about human nature?
I'm not sure war is in our DNA. Our propensity for violence may be in our DNA, but war comes with social organization. War is purposive and often calculating. People don't just rush helter-skelter into war. They think about it, plan and train for it, and it often takes a great deal of effort. The military knows this. They do a great deal of training to turn people who may not want to kill others or risk their lives into those who will fight. So our propensity to wage war goes along with our developing social organization. If you're nomadic, you can pick up and move into unoccupied space and get away from those who threaten you. But once you've settled down and become agriculturalists, it's much harder to move because you have something to defend. Plus, you have much more that someone else might want to take. Unfortunately, the better organized we get, the better we get at fighting each other.

Women in charge don't seem to be any less warlike than men.

But isn't the main purpose of social organization to protect people?
Even in protecting people, you may have to wage war. A really important factor in wars is greed for what others have. And along with that goes fear that someone is going to try to take what you have or in fact destroy your society altogether. It's often very hard to establish trust among different societies. Our tendency is more to be suspicious of each other. We've seen parts of the world where neighbors have lived with each other in harmony, but there is always the danger that this will break down.

Is this ultimately about tribalism? You're either in the in-group or the out-group, so we have this inherent mistrust and fear of the "other."
It does seem to run through a lot of human society, though I think it's something we can overcome. You can build institutions and values that make us more likely to trust each other. Religions are capable of bringing people into a larger grouping and insisting that we treat them as fellow human beings. And I think the European Union is in fact a very good example of how nations that formerly mistrusted and went to war with each other have learned to work together. But it's a painful process, and we've seen how easily societies can be turned against each other.

You said war has become a much bigger problem once people settled down and organized into large groups. But there does seem to be quite a lot of anthropological evidence that early hunter-gatherers and foraging societies were also warlike.
We always want to think there might be a kinder and gentler world. And we've often had this picture of people in the distant past living with each other in harmony, getting what they needed, enjoying their leisure, not fighting violently with each other. But the evidence really seems to be that fighting and violence goes back a very long way. The remaining hunter-gatherer societies in the world which have been studied often show very high rates of organized violence and death.

Wasn't this the old debate between Rousseau and Thomas Hobbes?
Rousseau said the trouble came when social organization led us into becoming more confrontational with

each other, whereas Hobbes said if you were to go back to the ancient world, the primitive world, you would find it very nasty indeed because there would be no central government and no way of controlling the impulses of people to fight with each other. For Hobbes, this was a good thing. The development of a big state, the Leviathan, had a monopoly of force which could maintain order in its own territories and defend its people against those who would try to destroy it.

Do you think Hobbes was right?
I do share his rather pessimistic view. But where he was wrong is that he thought the international order would always be anarchic and sort of dog against dog. We've been thinking for a long time about how we can build international institutions and norms which will get rid of the need for war. To go back to the example of the European Union, who would have predicted 100 years ago that the former enemies of Britain, France, and Germany would be living together and cooperating with each other? It's possible to move beyond war as a way of settling differences among nations. We can use courts, arbitration, and sanctions.

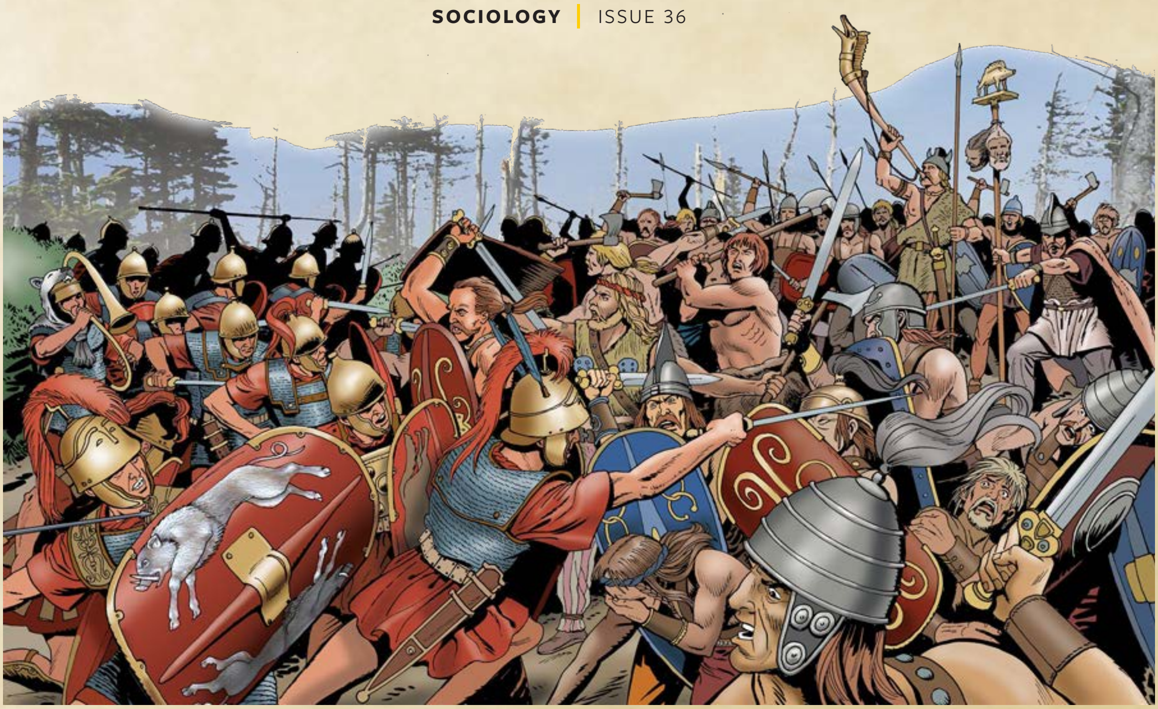
But the groups willing to wage war have often prospered.
Up to a point. They have often got themselves into wars that have cost them dearly as well. Charles Tilly has argued very persuasively that war has helped to create bigger states that benefit those who live within their borders because they provide more stability and security. The Roman Empire was built through war, but those who lived inside the Roman Empire enjoyed a higher standard of living and could travel freely because the roads and seas were safe. Trade could move through all the Roman territories because of the security it offered. It's very striking that people wanted to move into the Roman Empire, not out, because life was better inside it. The Romans were very tolerant of religious beliefs, but they did expect people to revere the emperor and obey certain customs and laws. So force wasn't the only secret to the Roman Empire's success.

How do most wars get started?
There are many reasons. Someone insults someone, someone marries someone, mistakes happen. But I tend to see it as greed—you have something that someone else wants. Maybe that's territory, maybe it's silver or gold, or maybe they want to make your people into slaves. You may also go to war out of fear that someone's about to attack you or because you fear for your survival. The final category is what I call ideas and ideologies we believe in. Religion can do that. If you want to build a paradise on Earth or you want to achieve your salvation in eternity, you may go to war because you'll feel less frightened of death and you're part of a much greater cause. Nationalism can be the same thing. You will fight and die for a nation because you're fighting for something bigger than yourself. Or you will fight in a civil war because you have different views on who should control that society and where that society should be going.

Don't civil wars tend to be the bloodiest wars?
They tend to be the worst because they are wars of ideologies, whether it's building socialism on Earth or paradise in the afterlife. It's almost a moral imperative to eliminate anyone who opposes you because they are standing in the way of the greater good of humanity. You feel no compunction in removing them from the face of the Earth. That is why such wars are so cruel. In a civil war, you're not just fighting those soldiers out in the field. You're fighting the whole society because it is wrong. Even the children are wrong. Even the old people are wrong. There's no one innocent in such wars.

You also write about the importance of contingency in war. A particular person becomes the leader or an accident triggers a war.
Many historians would disagree, but I think accident and contingency play quite a role in history. When the French Revolution broke out, Napoleon Bonaparte was a young man from not a particularly distinguished family from the island of Corsica, who was at a military academy. But he wouldn't have had a hope of rising to be a distinguished general if it hadn't been for the French Revolution. That revolution swept away the old order, so one of the great military geniuses of history had an opportunity he wouldn't have had in any other time or place.

And accident, too. I've come to the conclusion that the First World War could have been avoided. There



WHAT IT'S GOOD FOR The Roman Empire was built through war, but those who lived inside the Roman Empire enjoyed a higher standard of living and could travel freely because the roads and seas were safe, explains Margaret MacMillan.

MASSIMO TODARO / SHUTTERSTOCK

had been previous crises before 1914 when European countries had blustered about fighting each other, and they pulled back. In 1914, there was still the hope that this could be done, and I think they went too far without realizing it. The archduke got assassinated in Sarajevo. The Austrians decided, therefore, to try and destroy Serbia. Russia decided to defend Serbia. Germany decided to back Austria-Hungary. And they still thought they could pull back because they'd done it before. But they went too far and it became a question of national pride, which is very dangerous.

Have we come close to that kind of war again?
I think we came close in the Cold War. We talk about how nuclear weapons kept the balance of mutually assured destruction between the Soviet Union and the United States. But what has been absolutely terrifying to me is what's come out since the end of the Cold War—the moments when they very nearly did start shooting nuclear weapons at each other. In the Cuban Missile Crisis, we came an awful lot closer than we realize. There was a Russian submarine where the captain had the authority to fire a nuclear-tipped weapon, but someone persuaded him not to. There were times when technicians fed in the wrong training tapes and times on both sides when someone would see a flock of birds on the radar and think it was an incoming missile or an aircraft.

We've been talking about the horror of war, but you say war has also led to scientific advancements and sometimes more social equality. How far would you take that argument?
It is noticeable in history that sometimes it takes a very great challenge or great crisis to get us collectively to do things we wouldn't think of doing in normal times because they're too expensive or too difficult or too disruptive. A war is one of those challenges. So, too, is

a pandemic. You now see governments which had been talking about austerity suddenly spending money with a free hand because it has been absolutely essential to keep societies going. And war can do that as well. You know, a great many medical advances came as a result of war. Penicillin, for example, which was discovered in the interwar years of the 1920s, was considered too expensive to produce. Then the Second World War came along and suddenly it's not too expensive when you want to keep alive those who are fighting for you.

Didn't the modern computer revolution also come out of research funded by the U.S. Defense Department?
A lot of research during the Cold War and in fact during the Second World War led to the boom in science and technology in the United States. The Internet really is a product of research that was funded in American universities. And a lot of the success of Silicon Valley is based on research that the government funded for its own purposes for the Cold War, which turned out to have a peacetime application.

Wars have also led to more social equality. When the men went off to battle, the women on the home front ended up running things, which led to political changes.
Women in a number of countries had been agitating for the vote before the First World War, and the argument was that you don't have a stake in society in the way men do, so you should stay at home. In the First World War, there was a huge demand for men to go into the armies, and women found themselves doing jobs which they had not been considered capable of before. So they drove tractors on farms or they worked on assembly lines and in explosive factories. The government in Britain and a few other countries recognized that women had made a contribution to the war. The argument for denying them the vote just really didn't stand anymore.

Modern warfare is increasingly deadly because the technology is so much more lethal. Future wars will use more artificial intelligence, and you can imagine killer robots wiping out entire populations. Do you worry about the future of warfare?
I do. I find the high-tech weapons absolutely terrifying. Increasingly self-guided weapons are being developed—weapons which can make decisions for themselves and don't seem to need any human control. Who is ultimately going to control such weapons? And the amount of devastation they can do has increased as well. We worry about nuclear war, but ordinary explosives have become much more powerful in recent decades. We've also got whole new fields of war opening up with state-sponsored cyber attacks, which can threaten the whole infrastructure of a state.

I've come to the conclusion that the First World War could have been avoided.

Since humans seem to have this propensity to start wars, can we ever overcome these inherent tendencies within us?
I think we can overcome them. I'm so struck by the way Germany has changed. This was a society in the 19th and early 20th century that was imbued with militaristic values. The military was the noblest and best part of the nation, but that's completely gone. Germany is a different society and a different country. Sweden is another example. During the Thirty Years War in the 17th century, if you heard Swedish soldiers were coming anywhere near, you panicked because they were so violent and so ruthless. Now Sweden is a very different country committed to peacekeeping and international cooperation. Most European countries have moved well away from military values and away from thinking that war is a useful tool of state. It is now unthinkable that any European country will go to war with another European country. I do think it's absolutely possible and indeed very hopeful that we can move into societies which don't see war as something that should ever be used.

STEVE PAULSON is the executive producer of Wisconsin Public Radio's nationally syndicated show To the Best of Our Knowledge. He's the author of *Atoms and Eden: Conversations on Religion and Science*.

If Aliens Exist, Here's How We'll Find Them

Two esteemed astrophysicists peer into the future of space exploration

BY MARTIN REES & MARIO LIVIO

SUPPOSE ALIENS EXISTED, and imagine that some of them had been watching our planet for its entire four and a half billion years. What would they have seen? Over most of that vast timespan, Earth's appearance altered slowly and gradually. Continents drifted; ice cover waxed and waned; successive species emerged, evolved, with many of them becoming extinct.

But in just a tiny sliver of Earth's history—the last hundred centuries—the patterns of vegetation altered much faster than before. This signaled the start of agriculture—and later urbanization. The changes accelerated as the human population increased.

Then came even faster changes. Within just a century, the amount of carbon dioxide in the atmosphere began to rise dangerously fast. Radio emissions that couldn't be explained by natural processes appeared and something else unprecedented happened: Rockets launched from the planet's surface escaped the biosphere completely. Some spacecraft were propelled into orbits around the Earth; others journeyed to the moon, Mars, Jupiter, and even Pluto.

If those hypothetical aliens continued to keep watch, what would they witness in the next century? Will a final spasm of activity be followed by silence due to climate change? Or will the planet's ecology stabilize? Will there be massive terraforming? Will an armada of spacecraft launched from Earth spawn new oases of life elsewhere?

PAULISTA / SHUTTERSTOCK

It's in deep space that non-biological brains may develop powers that humans can't even imagine.

Let's think specifically about the future of space exploration. Successful missions such as Viking, Cassini, New Horizons, Juno, and Rosetta were all done with last-century technology. We can realistically expect that during this century, the entire solar system—planets, moons, and asteroids—will be explored by flotillas of robotic craft.

Will there still be a role for humans in crewed spacecraft?

There's no denying that NASA's new Perseverance rover speeding across the Jezero crater on Mars may miss some startling discoveries that no human geologist could reasonably overlook. But machine learning is advancing fast, as is sensor technology. In contrast, the cost gap between crewed and autonomous missions remains huge.

We believe the future of crewed spaceflight lies with privately funded adventurers like SpaceX and Blue Origin, prepared to participate in a cut-price program far riskier than western nations could impose on publicly supported projects. These ventures—bringing a Silicon-Valley-type culture into a domain long-dominated by NASA and a few aerospace conglomerates—have innovated and improved rocketry far faster than NASA or the European Space Agency have done. The future role of the national agencies will be attenuated—becoming more akin to an airport rather than to an airline.

The most crucial impediment to space flight stems from the intrinsic inefficiency of chemical fuel, and the requirement to carry a weight of fuel far exceeding that of the payload. So long as we are dependent on chemical fuels, interplanetary travel will remain a challenge. Nuclear power could be transformative. Allowing much higher in-course speeds would drastically cut the transit times in the solar system, reducing not only astronauts' boredom, but their exposure to damaging radiation. It's more efficient if the fuel supply can be on the ground; for instance, propelling spacecraft into orbit via a "space elevator"—and then using a "star-shot"-type laser beam generated on Earth to push on a "sail" attached to the spacecraft.

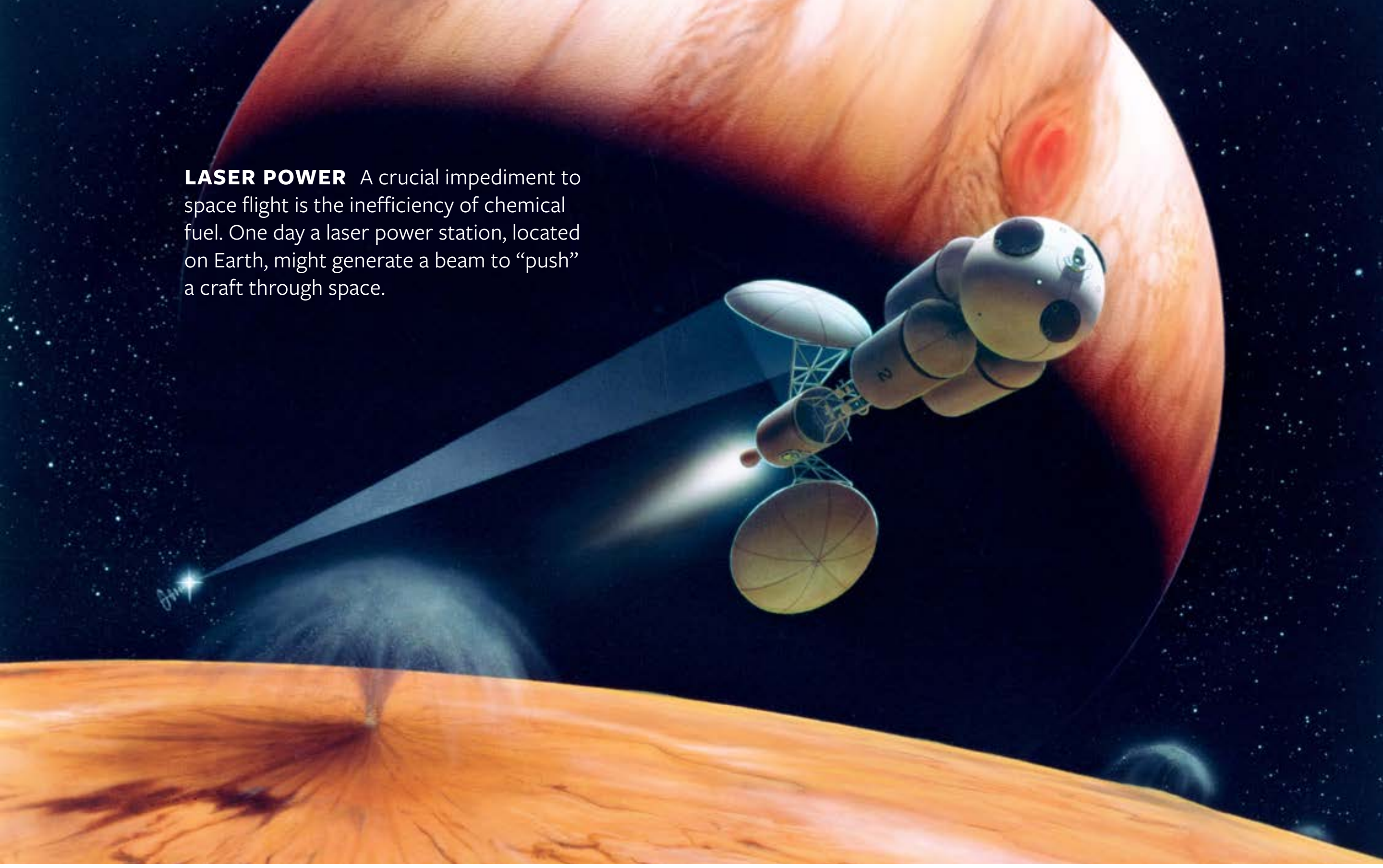
By 2100, thrill seekers in the mold of Felix Baumgartner (the Austrian skydiver who in 2012 broke the sound barrier in free fall from a high-altitude balloon) may have established bases on Mars, or maybe even on asteroids. Elon Musk has said he wants to die on Mars—"but not on impact." It's a realistic goal, and an alluring one to some.

But don't expect mass emigration from Earth. It's a dangerous delusion to think that space offers an escape from Earth's problems. We've got to solve those here. Coping with climate change or the COVID-19 pandemic may seem daunting, but it's a piece of cake compared to terraforming Mars. There's no place in our solar system that offers an environment even as clement as the Antarctic or the top of Mount Everest. Simply put, there's no Planet B for ordinary risk-averse people.

Still, we (and our progeny here on Earth) should cheer on the brave space adventurers. They have a pivotal role to play in spearheading the post-human future and determining what happens in the 22nd century and beyond.

PIONEER EXPLORERS will be ill-adapted to their new habitat, so they will have a compelling incentive to redesign themselves. They'll harness the super-powerful genetic and cyborg technologies that will be developed in coming decades. This might be the first step toward divergence into a new species.

Organic creatures need a planetary surface environment on which life could emerge and evolve. But if post-humans make the transition to fully inorganic intelligence, they won't need an atmosphere. They may even prefer zero-gravity, especially for constructing massive artifacts. It's in deep space that non-biological brains may develop powers that humans can't even imagine.



LASER POWER A crucial impediment to space flight is the inefficiency of chemical fuel. One day a laser power station, located on Earth, might generate a beam to "push" a craft through space.

NASA / PAT RAWLINGS (SAIC)

There are chemical and metabolic limits to the size and processing power of organic brains. Maybe we are close to these limits already. But no such limits apply to or constrain electronic computers (still less, perhaps, quantum computers). So, by any definition of "thinking," the amount and intensity that can be achieved by organic human-type brains will be swamped by the cerebrations of AI.

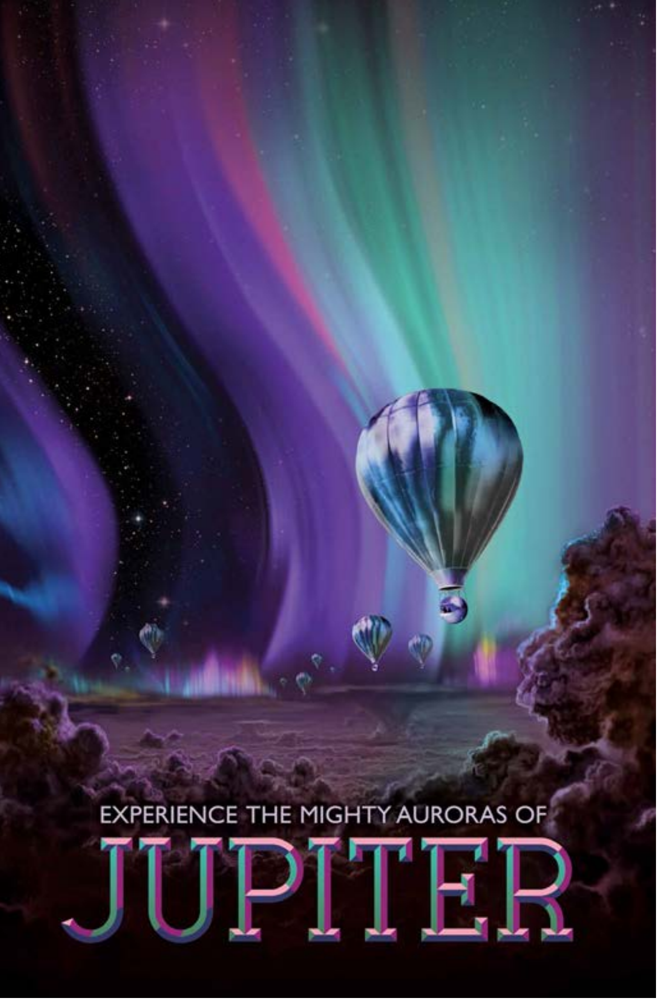
We are perhaps near the end of Darwinian evolution, but technological evolution of intelligent beings is only just beginning. It may happen fastest away from Earth—we wouldn't expect (and certainly wouldn't wish for) such rapid changes in humanity here on the Earth, though our survival may depend on ensuring the AI on Earth remains "benevolent."

Few doubt machines will gradually surpass or enhance more and more of our distinctively human capabilities. Disagreements are only about the timescale on which this will happen. Inventor and futurist Ray Kurzweil says it will be just a matter of a few decades. More cautious scientists envisage centuries. Either way, the timescales for technological advances are an instant compared to the timescales of the Darwinian evolution that led to humanity's emergence—and more relevantly, less than a millionth of the vast expanses of cosmic time ahead. The products of future technological evolution could surpass humans by as much as we have surpassed slime mold.

But, you may wonder, what about consciousness?

Philosophers and computer scientists debate whether consciousness is something that characterizes only the type of wet, organic brains possessed by humans, apes, and dogs. Would electronic intelligences, even if their intellects would seem superhuman, lack self-awareness? The ability to imagine things that do not exist? An inner life? Or is consciousness an emergent property that any sufficiently complex network will eventually possess? Some say it's irrelevant and semantic, like asking whether submarines can swim.

We don't think it is. If the machines are what computer scientists refer to as "zombies," we would not accord their experiences the same value as ours, and



SPACE TOURISM Private space companies should avoid the phrase "space tourism," write Martin Ress and Mario Livio. It lulls people into believing such ventures are routine and low-risk. They're more like extreme sports.

NASA / JET PROPULSION LABORATORY

We are near the end of Darwinian evolution, but technological evolution of intelligent beings is just beginning.

the post-human future would seem rather bleak. On the other hand, if they are conscious, we should welcome the prospect of their future hegemony.

What will their guiding motivation be if they become fully autonomous entities? We have to admit we have absolutely no idea. Think of the variety of bizarre motives (ideological, financial, political, egotistical, and religious) that have driven human endeavors in the past. Here's one simple example of how different they could be from our naive expectations: They could be contemplative. Even less obtrusively, they may realize it's easier to think at low temperatures, therefore getting far away from any star, or even hibernating for billions of years until the cosmic microwave background cooled down far below its current 3 degrees Kelvin. At the other edge of the spectrum, they could be expansionist, which seems to be the expectation of most who've thought about the future trajectory of civilizations.

Even if life had originated only on Earth, it need not remain a marginal, trivial feature of the cosmos. Humans could jump-start a diaspora whereby ever-more complex intelligence spreads through the galaxy, transcending our limitations. The "sphere of influence" (or some would envisage a "frontier of conquest") could encompass the entire galaxy, spreading via self-reproducing machines, transmitting DNA or instructions for 3-D printers. The leap to neighboring stars is just an early step in this process. Interstellar voyages—or even intergalactic voyages—would hold no terrors for near-immortals.

Moreover, even if the only propellants used were the currently known ones, this galactic colonization would take less time, measured from today, than the more than 500 million years elapsed since the Cambrian explosion. And even less than the 55 million years since the advent of primates, if it proceeds relativistically.

The expansionist scenarios would have the consequence that our descendants would become so conspicuous that any alien civilization would become aware of them.

THE CRUCIAL QUESTION REMAINS: Are there other expansionists whose domain may impinge on ours?

We don't know. The emergence of intelligence may require such a rare chain of events and happenstance contingencies—like winning a lottery—that it has not occurred anywhere else. That will disappoint SETI searchers and explain the so-called Fermi Paradox—the surprise expressed by physicist Enrico Fermi over the absence of any signs for the existence of other intelligent civilizations in the Milky Way. But suppose we are not alone. What evidence would we expect to find?

Suppose that there are indeed many other planets where life emerged, and that on some of them Darwinian evolution followed a similar track to the one on Earth. Even then, it's highly unlikely that the key stages would be synchronized. If the emergence of intelligence and technology on a planet lags significantly behind what has happened on Earth (because, for example, the planet is younger, or because some bottlenecks in evolution have taken longer to negotiate) then that planet would reveal no evidence of ET. Earth itself would probably not have been detected as a life-bearing planet during the first 2 billion years of its existence.

But around a star older than the sun, life could have had a head start of a billion years or more. Note that the current age of the solar system is about half the age of our galaxy and also half of the sun's predicted total lifetime. We expect that a significant fraction of the stars in our galaxy are older than the sun.

The history of human technological civilization is measured in mere millennia. It may be only a few more centuries before humans are overtaken or transcended by inorganic intelligence, which will then persist, continuing to evolve on a faster-than-Darwinian timescale for billions of years. Organic human-level intelligence may be, generically, just a brief interlude before the machines take over, so if alien intelligence had evolved similarly, we'd be most unlikely to catch it in the brief sliver of time when it was still embodied in that form. Were we to detect ET, it would be far more likely to be electronic where the dominant creatures aren't flesh and blood—and perhaps aren't even tied to a planetary surface.

Astronomical observations have now demystified many of the probability factors in the so-called Drake Equation—the probabilistic attempt traditionally used to estimate the number of advanced civilizations in the Milky Way. The number of potentially habitable planets has changed from being completely unknown only a couple of decades ago to being directly determined from the observations. At the same time, we must reinterpret one of the key factors in the Drake equation. The lifetime of an organic civilization may be millennia at most. But its electronic diaspora could continue for billions of years.

Extraterrestrial civilization might consist of a swarm of microscopic probes that could have evaded notice.

If SETI succeeded, it would then be unlikely that the signal would be a decodable message. It would more likely reveal a byproduct (or maybe even a malfunction) of some super-complex machine beyond our comprehension.

The habit of referring to "alien civilizations" may in itself be too restrictive. A civilization connotes a society of individuals. In contrast, ET might be a single integrated intelligence. Even if messages were being transmitted, we may not recognize them as artificial because we may not know how to decode them, in the same way that a veteran radio engineer familiar only with amplitude-modulation (AM) transmission might have a hard time decoding modern wireless communications. Indeed, compression techniques aim to make the signal as close to noise as possible; insofar as a signal is predictable, there's scope for more compression.

SETI so far has focused on the radio part of the spectrum. But we should explore all wavebands, including the optical and X-ray band. We should also be alert for other evidence of non-natural phenomena or activity. What might then be a relatively generic signature? Energy consumption, one of the potential hallmarks of an advanced civilization, appears to be hard to conceal.

One of the most plausible long-term energy sources available to an advanced technology is starlight. Powerful alien civilizations might build a megastructure known as a "Dyson Sphere" to harvest stellar energy from one star, many stars, or even from an entire galaxy.

WE'RE LISTENING The Allen Telescope Array, located at the Hat Creek Observatory in the Cascade Mountains, about 300 miles north of San Francisco, makes astronomical observations and stays attuned to signs of extraterrestrial life.

SETH SHOSTAK / SETI INSTITUTE

The other potential long-term energy source is controlled fusion of hydrogen into heavier nuclei. In both cases, waste heat and a detectable mid-infrared signature would be an inevitable outcome. Or, one might seek evidence for massive artifacts such as the Dyson Sphere itself. Intriguingly, it's worth looking for artifacts within our own solar system: Maybe we can rule out visits by human-scale aliens, but if an extraterrestrial civilization had mastered nanotechnology and transferred its intelligence to machines, the "invasion" might consist of a swarm of microscopic probes that could have evaded notice. Still, it would be easier to send a radio or laser signal than to traverse the mind-boggling distances of interstellar space.

FINALLY, LET'S FAST FORWARD not for just a few millennia, but for an astronomical timescale, millions of times longer. As interstellar gas will be consumed, the ecology of stellar births and deaths in our galaxy will proceed more gradually, until jolted by the environmental shock of a collision with the Andromeda galaxy, about 4.5 billion years hence. The debris of our galaxy, Andromeda, and their smaller companions (known as the Local Group) will aggregate into one amorphous (or perhaps elliptical) galaxy. Due to the accelerating cosmic expansion, distant galaxies will move farther away, receding faster and faster until they disappear—rather like objects falling into a black hole—encountering a horizon beyond which they are lost from view and causal contact. But the remnants of our Local Group could continue for a far longer time. Long enough perhaps for what has been dubbed a "Kardashev Type III" phenomenon, in which a civilization is using the energy from one or more galaxies, and perhaps even that released from supermassive black holes, to emerge as the culmination of the long-term trend for living systems to gain complexity and negative entropy (a higher degree of order).

Everything we've said is consistent with the laws of physics and the cosmological model.

The only limitations set by fundamental physics would be the number of accessible protons (since those can in principle be transmuted into any elements), and the total amount of accessible energy ($E=mc^2$, where m is mass and c is the speed of light) again transformable from one form to another.

Essentially all the atoms that were once in stars and gas could be transformed into structures as intricate as a living organism or silicon chips but on a cosmic scale. A few science-fiction authors envisage stellar-scale engineering to create black holes and wormholes—concepts far beyond any technological capability that we can imagine, but not in violation of basic physical laws.

If we want to go to further extremes, the total mass-energy content in the Local Group isn't the limit of the available resources. It would still be consistent with physical laws for an incredibly advanced civilization to lasso the galaxies that are receding because of the cosmic expansion of space before they accelerate and disappear over the horizon. Such a hyper-intelligent species could pull them in to construct a segment resembling Einstein's original idea of a static universe in equilibrium, with a mean density such that the cosmic repulsion caused by dark energy is precisely balanced by gravity.

Everything we've said is consistent with the laws of physics and the cosmological model as we understand them. Our speculations assume that the repulsive force causing cosmic acceleration persists (and is described by dark energy or Einstein's cosmological constant). But we should be open-minded about the possibility that there is much we don't understand.

Human brains have changed relatively little since our ancestors roamed the African savannah and coped with the challenges that life then presented. It is surely remarkable that these brains have allowed us to make sense of the quantum subatomic world and the cosmos at large—far removed from the common sense, everyday world in which we have evolved.

Scientific frontiers are now advancing fast. But we may at some point hit the buffers. There may be phenomena, some of which may be crucial to our long-term destiny, that we are not aware of any more than a gorilla comprehends the nature of stars and galaxies. Physical reality could encompass complexities that neither our intellect nor our senses can grasp. Electronic brains may have a rather different perception of reality. Consequently, we cannot predict or perhaps even understand the motives of such brains. We cannot assess whether the Fermi paradox signifies their absence or simply their preference.

Conjectures about advanced or intelligent life are shakier than those about simple life. Yet there are three features that may characterize the entities that SETI searches could reveal.

- Intelligent life is likely not to be organic or biological.
- It will not remain on the surface of the planet where its biological precursor emerged and evolved.
- We will not be able to fathom the intentions of such life forms.

Two familiar maxims should pertain to all SETI searches. On one hand, "absence of evidence isn't evidence of absence," but on the other, "extraordinary claims require extraordinary proof."

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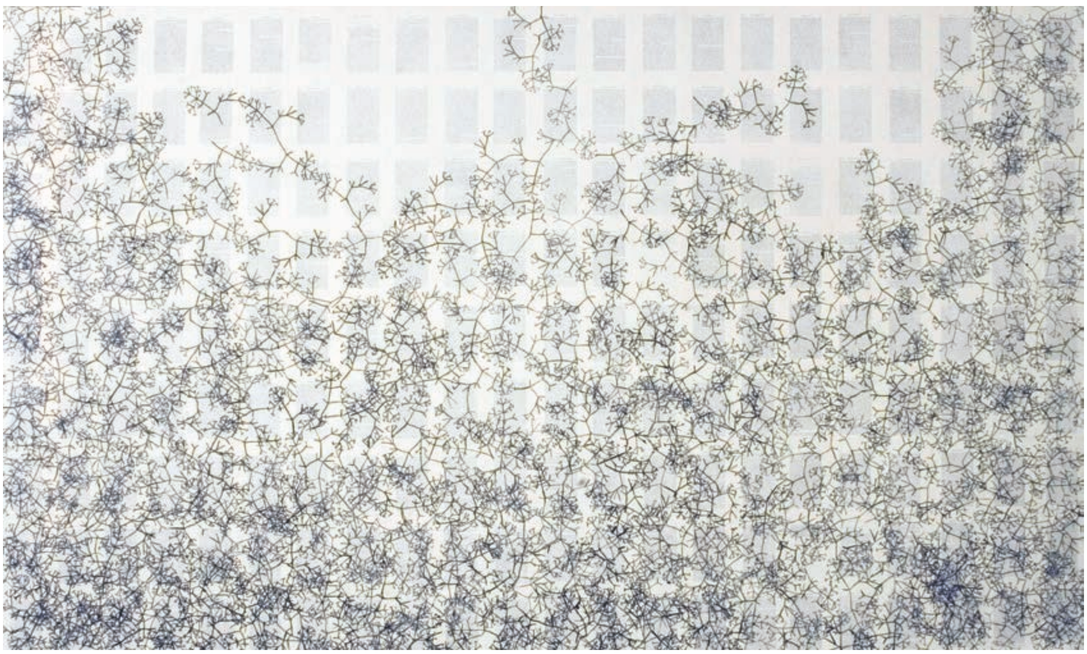

TIM ROLLINS + K.O.S. (Kids of Survival), *On the Origin of Species (after Darwin)*, 2008-2009, India ink, graphite transfer, matte acrylic, and book pages on canvas, 72 x 120 inches, collection of the National Academy of Sciences.

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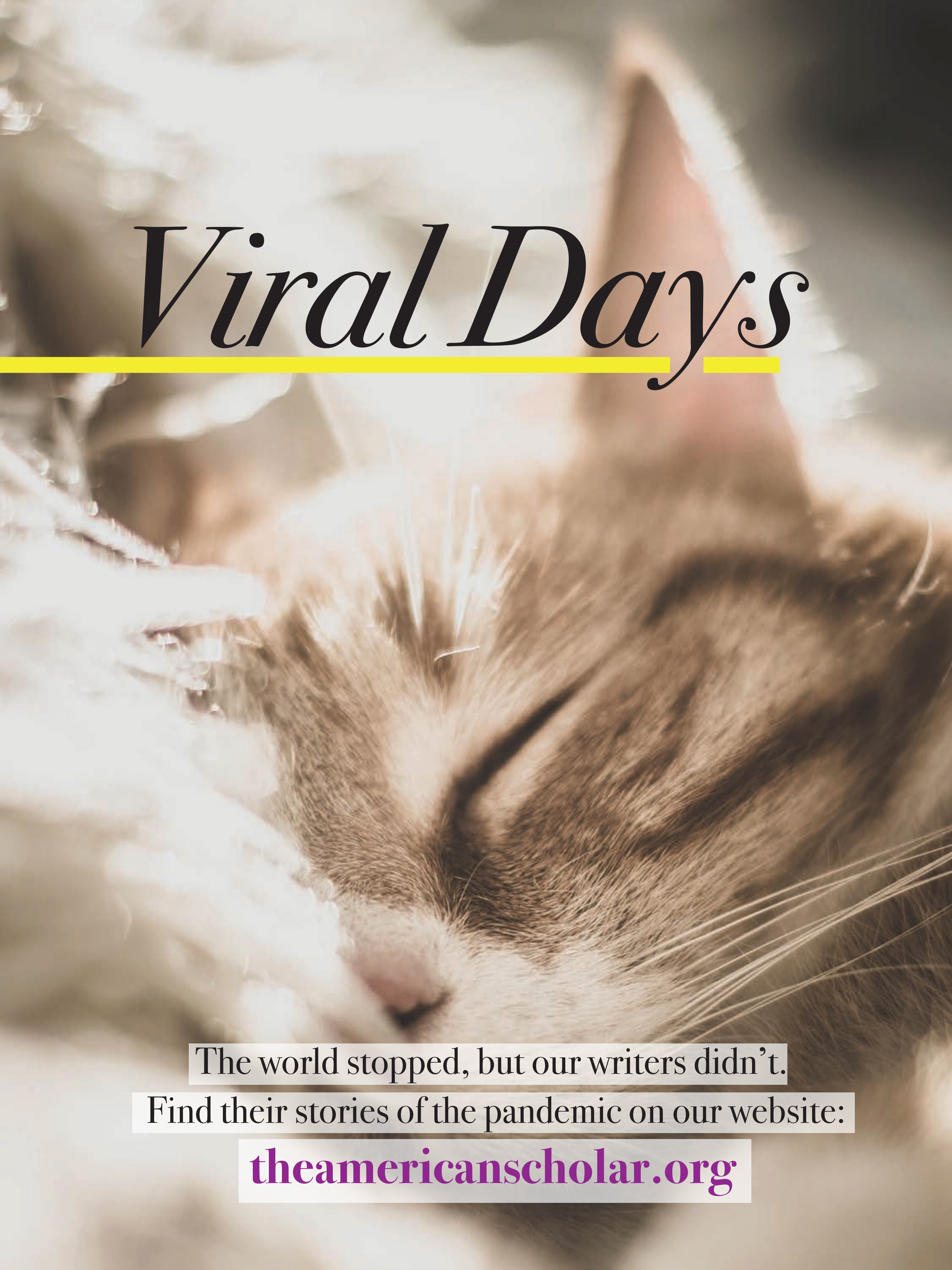
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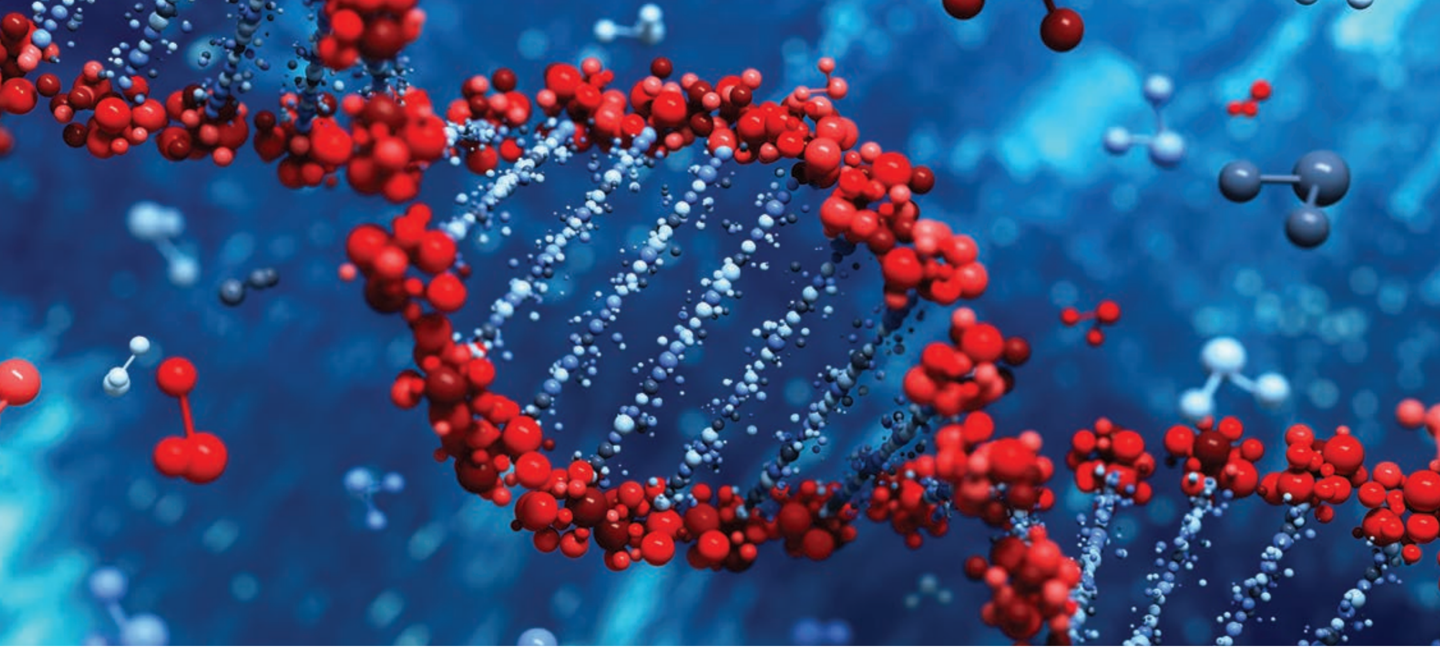

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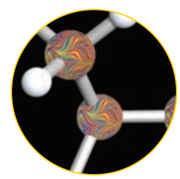

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Heidi Hammel

The planetary astronomer on the enigmatic "ice giants" Neptune and Uranus

INTERVIEW BY COREY S. POWELL

FORGOTTEN PLANETS

Neptune and Uranus are enigmas because they're so far away. That's what first attracted me to them. I knew any work I could do to study them would make a difference. Since then, we've developed sophisticated astronomical tools like Hubble and the Keck 10-meter telescopes, but we still know so little about them. The other thing that's happened is we have discovered thousands of planets around other stars, exoplanets. The largest number of them seem to be intermediate-size planets in the super-Earth, sub-Neptune size range. We don't have any sub-Neptunes in our solar system; Uranus and Neptune are the closest thing here to analogs to the most populous type of exoplanet that we know of.

WEATHER

If you don't like the weather on Neptune, wait 10 minutes because it's going to change. With Hubble and Keck we've tracked the disappearance and appearance of multiple Great Dark Spots in both hemispheres. Whatever's going in Neptune's atmosphere, it's easy to form a Great Dark Spot and it's easy to make it go away. And there's always lots of bright clouds. Why are they there? What's causing them? One theory is that Neptune has such a cold atmosphere that it's almost like friction-free. On Uranus, meanwhile, we find the equatorial region has a really gorgeous wave pattern, and there are lots of small storms all around the polar region. It's all so interesting and unexpected.

BAD JOKES

The United States population is so sophomoric. We can't get past the whole, "NASA's going to send a probe to 'Your Anus.'" There's actually a big debate about this. Is it positive or negative? Some people say, "Hey, any publicity is good publicity. You could own the joke." And I'm like, "Yeah, it's a little too scatological for me to own." I have a whole Word document of the jokes, and one of these days I'm going to post it on Twitter: "The discovery of methane on Uranus," "We found a dark ring around Uranus," "One of the main rings around Uranus is bright red." It just goes on and on. You can own it as much as you want, but what sank the SETI program 30 years ago was one senator saying, "NASA's spending money on little green men." It's sad, but there it is.

URANUS VS NEPTUNE

I would probably choose Neptune. Number one, you're guaranteed a fantastic and dynamic atmosphere to look at, whereas with Uranus we don't know. The number two reason is Triton. Triton is an active world. It has cryovolcanos erupting on it right now. It has an atmosphere that we can detect from Earth. We can observe that the temperature and pressure are changing, so we know that the atmosphere is moving around. We only saw part of Triton [with Voyager 2 in 1989] and what we saw was very young and fresh. Triton's awesome. I would like to map it out really well. I'd like to know if there's an ocean underneath the icy crust.

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