

NAUTILUS

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Reviving a forgotten solution

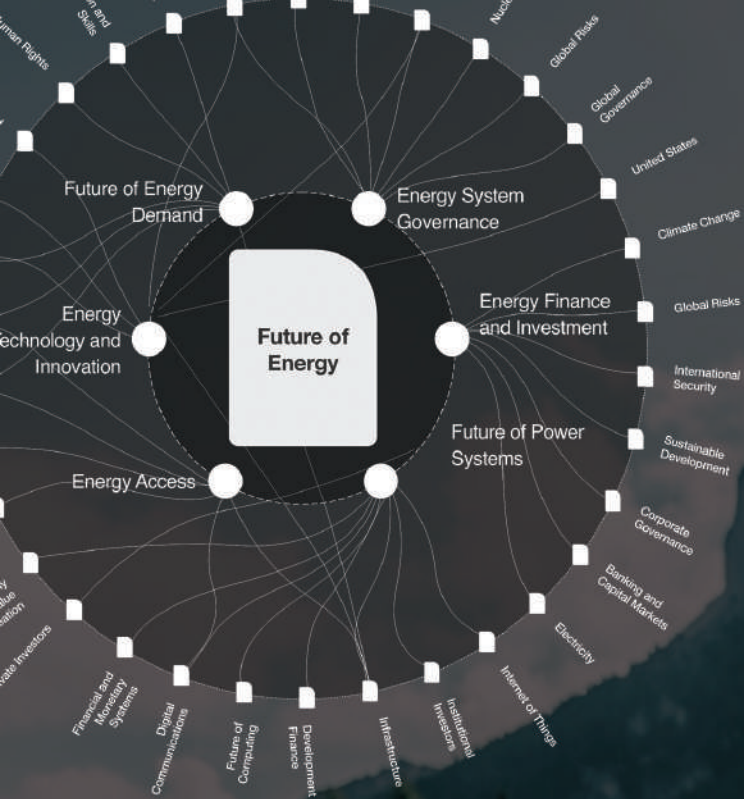
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TAKE IT FROM A SUBMARINER
How to live in close quarters



Life Hangs in the Balance

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Egypt ready to resume talks with Ethiopia, Sudan over Nile dam



Nile dam talks stall again amid Egyptian-Ethiopian dispute



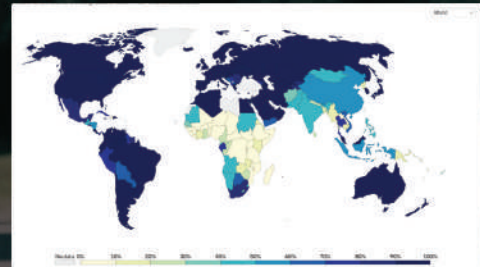
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Egypt ready to resume talks with Ethiopia, Sudan over Nile dam

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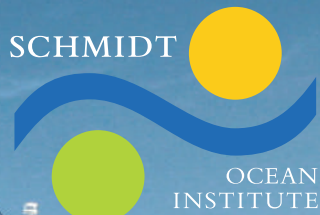
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NAUTILUS

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NAUTILUS *Next*

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All the World's a Stage

BY KEVIN BERGER

DENNIS CARROLL DIDN'T SOUND CONFIDENT global societies would join forces to stop the next pandemic. During our interview ("The Man Who Saw the Pandemic Coming"), the expert in zoonotic diseases said science, which has shown its best face during the crisis, only takes societies so far. "Think of the syllogism from Socrates: right thinking leads to right action," Carroll said. "We know that's not the case. Your thoughts can be absolutely right on, but your practices can be completely divergent."

I couldn't stop thinking about Carroll's note of realpolitik gloom. After all the suffering and deaths, we must now realize we can't keep carving the environment into our own image. We're bulldozing animal habitats and driving the lethal viruses that thrive in them into us. We must now understand the consequences. Wanting to chase that thought deeper into my mind's woods, I wrote a sequel to my interview with Carroll, this issue's cover story, "We Are the Environment."

During my research, I had great conversations, notably with Shaid Naeem, a professor of ecology at Columbia University, about the role humans play on the world's environmental stage. It's easy to cast ourselves as villains, but we aren't all Iago with a chainsaw.

"Many creative thinkers have realized the human population is quite vulnerable," Naeem said. "But it takes something like Hurricane Sandy or massive wildfires in Australia to make us realize we're still a biological entity that's not capable of controlling the world. We're still subject to the rules of ecology."

We have the smarts to act in concert with nature. We can restrain from building another tract of ranch houses in wilderness areas where viruses lie in wait, ready to strike like rattlesnakes. Why don't we? "We're distracted," Naeem said. "We're distracted by xenophobia and fear of sexual diversity and the lust for fast cars. We're distracted by all these things."

Distraction blinds us to our interconnected nature. "When you take a breath of air, that could be an oxygen molecule that cycled through a Tyrannosaurus Rex 60 million years ago," Naeem said. "When a plant converts a ray of sunlight into a carbon molecule, and you have that in your sandwich, you are connected to the sun. As Carl Sagan said, we are star dust. It takes the death of stars to produce the elements that make us. Most of the water on this planet was delivered on asteroids and comets. We are connected to a delivery system in the universe that's measured in light-years."

This issue of *Nautilus*, created in a time of tragedy, shows the world is indeed a stage, and that one person—a citizen, a scientist, a policymaker—must act with others. "If not, the whole team loses because of a few bad actors," Naeem said. "We don't want to be bad actors."



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Readers Respond

Comments and letters about stories from print issue 30.

“CONSCIOUSNESS ISN’T SELF-CENTERED”

The problem with the field theory of mind is that it comes straight from Hegel and tries to bundle that up with a Marxist base of materialism. In reality, both matter and consciousness exist. We know about matter via extrospection (or sense perception) and we know about mind or consciousness via introspection (the only direct means of you knowing that you are conscious at all). Matter exists, and consciousness exists; but matter is out there in the universe, while consciousness (or man’s selfishly centered mind) is in here. Matter is not made of consciousness, and consciousness is not made of matter—and yet, they both exist. Saying consciousness is a type of space-time field is putting the cart before the horse.

—Thomas M. Miovas, Jr.

“WE ARE ALL BEWILDERED MACHINES”

I am not a machine, nor are you. I am an organism, a living being comprised of billions of other living cells; capable of propagation and reproduction, and the ability to metabolize food that, in addition to providing fuel for my body to work, provides nutrients for the function of brain, nerves, cells, and tissue and organ repair when damaged. A machine is engineered and built with a specific function, does not have the ability to reproduce, let alone produce

genetically unique offspring, self-repair itself by ingesting nutrients that also serve as a fuel and catalyst for other function within its framework. Calling a human being a machine is oversimplification of the grossest sort. It’s like calling a computer sand because it has silicone components.

—Jon Goff

I didn’t agree with all you said, but I liked how you took the journey to a whole new look at this subject.

—Lois Pyles

“AN EXISTENTIAL CRISIS IN NEUROSCIENCE”

I don’t think anything can (or should) be big enough to understand itself. A similar phenomenon has occurred in the application of physics of matter to energy conversion in war technology. Our ability to understand and control only 1 percent of matter and convert that into energy has produced nuclear weapons capable of destroying our existence in minutes. Any further increases to such technology is very unlikely to be compatible with our survival. I think the same will ring true with too much of an attempt to understand (and manipulate) our mind and soul. I believe to some extent our minds and the universe must remain unknowable in order for it to continue existing. Perfect knowledge of our identity would abolish free will and our meaning for life.

—Selcuk Olzker

“WE ARE ALL ANCIENT MAPMAKERS”

Great article explaining the distinction between “map” (or theory) and data! This applies not just to geography, but to all of science, including physics. Science gets in trouble when theories get too far in front of data. Like the “infinite multiverse,” a theoretical construction with no data—a bit like Anaximander’s column.

—George Gantz



Nautilus welcomes reader responses.

Please email letters@nautil.us.

All letters are subject to editing.

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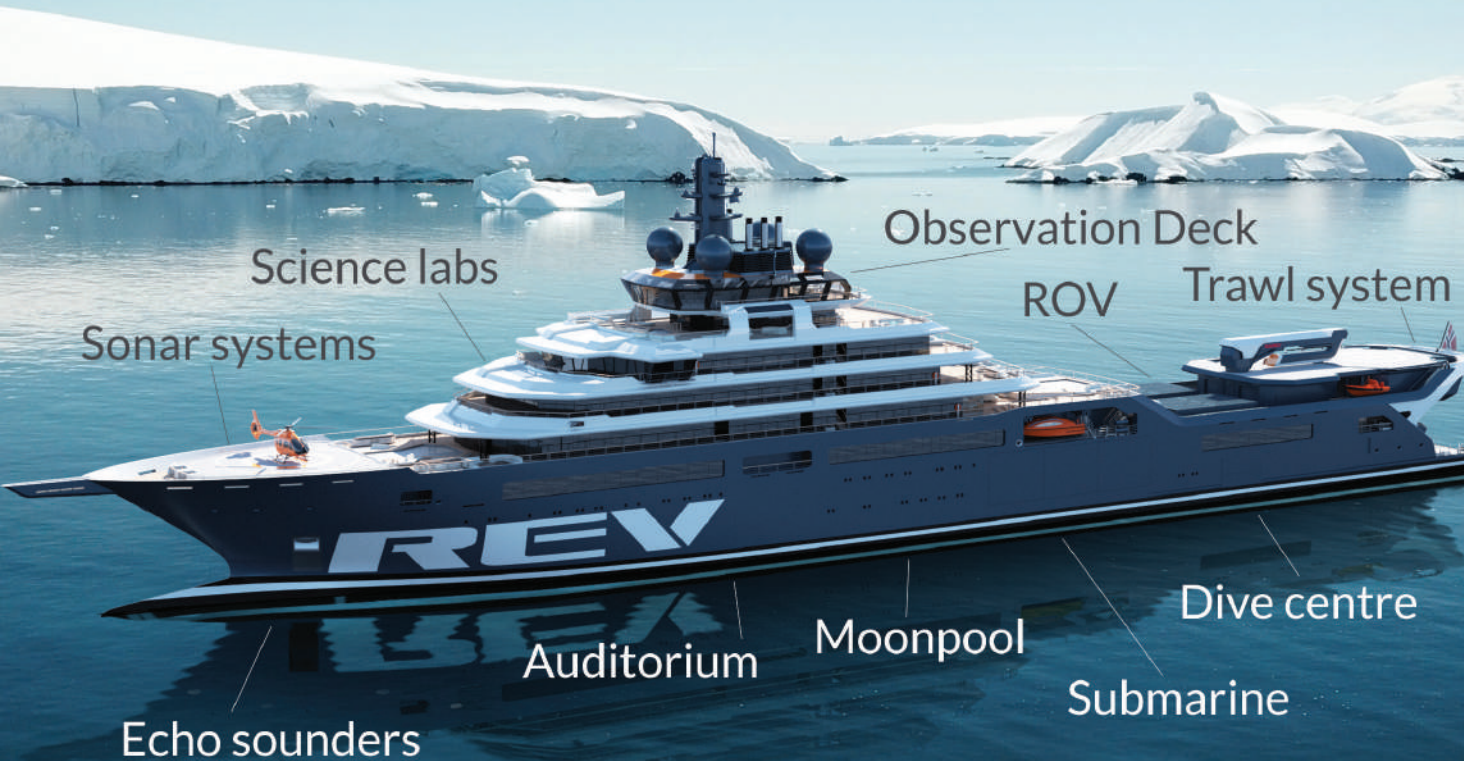
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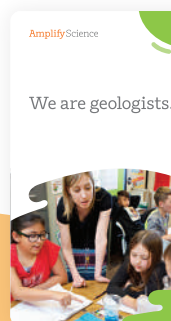
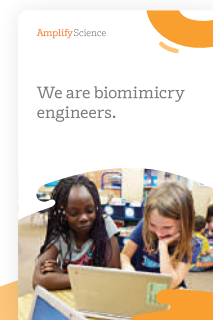
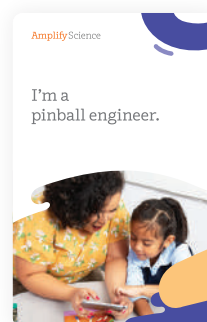
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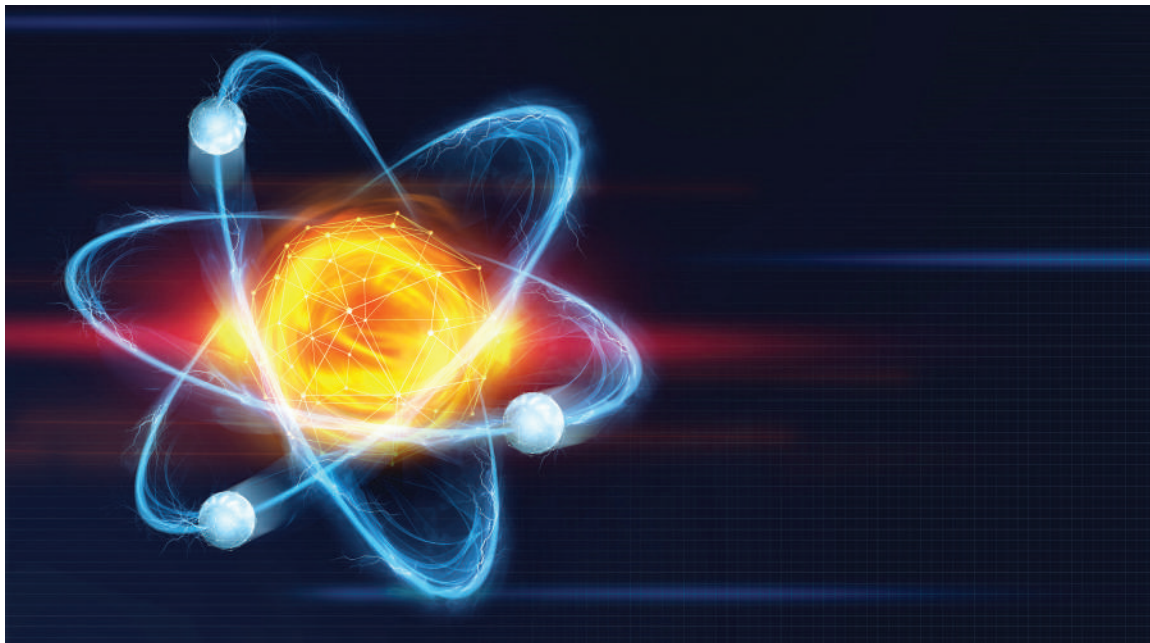




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Preludes



PHYSICS

Electrons May Very Well Be Conscious

IN MAY, THE COVER of *New Scientist* asked, “Is the Universe Conscious?” Mathematician and physicist Johannes Kleiner told author Michael Brooks that a mathematically precise definition of consciousness could mean that the cosmos is suffused with subjective experience.

While there are many versions of panpsychism, the version I find appealing is known as constitutive panpsychism. It states that all matter has some associated mind or consciousness, and vice versa. Where there is mind there is matter and where there is matter there is mind. As modern panpsychists, including Alfred North Whitehead, have argued, all matter has some capacity for feeling, albeit highly rudimentary feeling in most configurations of matter.

Panpsychists look at the many rungs on the complexity ladder of nature and see no obvious line between mind and no-mind. Philosopher Thomas Nagel famously asked in 1974 what is it like to be a bat, to echolocate and fly? We can’t know with any certainty, but we can reasonably infer, based on observation of their complex behaviors and the close genetic kinship between all mammals and humans—and the fact that evolution proceeds incrementally—that bats have a rich inner life. By the same logic, we can look steadily at less-complex forms of behavior that allow us to reasonably infer some kind of mind associated with all types of matter. Yes, including even the lowly electron.

While inanimate matter doesn’t evolve like animate matter, inanimate matter does behave. It does things.

YURCHANKA SIARHEI / SHUTTERSTOCK

Electrons may have some type of extremely rudimentary mind.

It responds to forces. Electrons move in certain ways that differ under different experimental conditions. These types of behaviors have prompted respected physicists to suggest that electrons may have some type of extremely rudimentary mind. The late Freeman Dyson stated in his 1979 book, *Disturbing the Universe*, that “the processes of human consciousness differ only in degree but not in kind from the processes of choice between quantum states which we call ‘chance’ when made by electrons.” Quantum chance is better framed as quantum choice—choice, not chance, at every level of nature. David Bohm, another well-known physicist, argued similarly: “The ability of form to be active is the most characteristic feature of mind, and we have something that is mind-like already with the electron.”

Theoretical physicist Sabine Hossenfelder, author of the 2018 book *Lost in Math*, has taken a contrary position. “If you want a particle to be conscious, your minimum expectation should be that the particle can change,” she argued. “It’s hard to have an inner life with only one thought. But if electrons could have thoughts, we’d long have seen this in particle collisions because it would change the number of particles produced in collisions.”

Yet “change” means many different things, including position in space over time. What Dyson is getting at in his remark about electrons and quantum theory is that the probabilistic distribution-outcomes of quantum experiments (like the double-slit experiment) are better explained as the product, not of pure chance, but of numerous highly rudimentary choices by each electron in each moment about where and how to manifest.

Whitehead’s variety of panpsychism, still the most worked-out version of panpsychism today, re-envisioned the nature of matter in a fundamental way. For Whitehead, all actual entities, including electrons, atoms, and molecules, are “drops of experience” in that they enjoy at least a little bit of experience, a little bit of awareness.

Rather than being unchanging things moving around in a container of spacetime, Whitehead conceives of particles like electrons as a chain of successive iterations of a single electron that bear a strong likeness to each other in each iteration, but are not identical to each other. Each iteration is a little different than the last. There is no static and unchanging electron. The degree to which each iteration is more or less different than the last iteration is the place for an iota of choice, and mind. This iota of choice compounds upward and, through the course of biological evolution, results in the complex types of mind and choice that we humans and other mammals enjoy.

Many modern thinkers have come to embrace Whitehead and panpsychism to varying degrees. So, yes, there is plenty of room in modern physics for electrons to “think.”

— Tam Hunt

ENVIRONMENT

The Pandemic Can’t Lock Down Nature

N EEDING TO CLEAR MY HEAD, I went down to the Penobscot River. There they were, swimming with the mergansers, following an early pulse of river herring to the mouth of Kenduskeag stream: two harbor seals, raising sleek round heads for a few long breaths before rolling under the waves.

Evidently it’s not uncommon for seals to swim the couple dozen miles between Bangor, Maine, and the Atlantic Ocean, but I’d never seen them here before. They were a balm to my buzzing thoughts: What happens next? Will I become a vector of death to my elderly mother? Is the economy going to implode? For a precious few minutes there were only the seals and mergansers and the fish who drew them there, arriving as the Penobscot’s winter icepack broke and flowed to sea, a ritual enacted ever since glaciers retreated from this continental shelf.



The nonhuman world is free of charge; sunlight is a disinfectant, and physical distance is easily maintained.

The birds are the surest sign of spring's imminence. Downtown the house finches are holding daily concerts. Starlings are starting to replace their gold-streaked winter plumes with more iridescent garb. In the street today I saw two male

In the months ahead we can look to nature for these respites. The nonhuman world is free of charge; sunlight is a disinfectant, physical distance easily maintained, and no pandemic can suspend it. Nature offers not just escape but reassurance.

In 1946, in the aftermath of World War II, with the Nazi threat vanquished but the Cold War looming, George Orwell welcomed spring's arrival in London's bombed-out heart. "After the sorts of winters we have had to endure recently, the spring does seem miraculous, because it has become gradually harder and harder to believe that it is actually going to happen," he wrote in "Some Thoughts on the Common Toad." "Every February since 1940 I have found myself thinking that this time winter is going to be permanent. But Persephone, like the toads, always rises from the dead at about the same moment."

So she does. And so the slumbering earth warms to life. Two nights before the seals, two nights before World Health Organization declared a pandemic, before the NBA shut down with teams on the floor and fans in the seats, before the fright went beyond viral into logarithmic, was the Worm Moon: the full moon named for the imminent stir of earthworms in thawing soil.

mockingbirds joust above the pavement, their white wing-bars fluttering territorial semaphores, abandoning the contest only when a car nearly ran them down.

There are many quieter signs, too: pale tips of shrubs poised to grow, a spider rappelling off a low branch, fresh fox scat in the driveway. It's red from apples preserved under snow and lined with the fur of field mice and meadow voles whose secret winter tunnels are now revealed in the grass. Somewhere soon mother fox will give birth, nursing her blind hairless pups in underground peace.

Eastern comma butterflies will gather on the trunks of those apple trees and sip their rising sap. Not long after the first orange-belted bumblebee queens will appear, inspecting potential nest sites under fallen leaves and decomposing logs. Warm rainy nights will bring salamanders and newts, just a few spotted glistening inches long, some of them decades old, out from woodland hidey-holes and down ancient paths to vernal pool bacchanals held amidst a chorus of spring peepers. Woodland ephemerals will bloom in sunshine unfiltered by still-bare treetops. My favorite are trout lilies, colonies of which illuminate forest floors with a sea of bright yellow blossoms, petals falling once the canopy unfurls.

“The atom bombs are piling up in the factories, the police are prowling through the cities, the lies are streaming from the loudspeakers,” Orwell wrote, “but the earth is still going round the sun.”

At this point there’s no end of studies showing how nature is good for our health, how patients recover faster in hospital rooms with windows overlooking trees, how a mindful walk in the woods will lower stress and raise moods. All true, but at this moment something deeper and more urgent is offered. An affirmation of life.

Will the nightmare scenes out of Italy and Spain and now New York City spread across the land? How long will the pandemic last? Will it completely rend our already tattered social fabric? When can I again play hockey or go to a coffee shop or use a credit card machine without feeling like I’m risking my

own and other lives? Who will die? Nobody knows for sure, but in a few weeks the swallows will arrive, and tonight above the fields at dusk I heard the cries of woodcock.

Secretive, ground-dwelling birds with limpid black eyes and long, slender beaks attuned to the frequencies of earthworm-rustles, their feathers blend perfectly with leaf litter and old grass. They rely on this camouflage, going still rather than fleeing a walker’s approach, taking wing only as a last resort.

When they do, their flight is notable for its slowness and the quavering whistle of their wings. At no other time than in spring do they dare draw attention, much less put on a show: calling out, with an urgent nasal buzz best described as a *peent*, and flying straight upward before spiraling against a darkening sky.

—Brandon Keim

PSYCHOLOGY

The Case Against Thinking Outside the Box

MANY OF US ARE STUCK NOW, sheltered in our messy dwellings. A daily walk lets me appreciate the urban landscaping; but I can’t stop to smell anything because a blue cotton bandana shields my nostrils. Indoors, constant digital dispatches chirp to earn my attention. I click on memes, status updates, and headlines, but everything is more of the same. How many ways can we repackage fear and reframe optimism? My thoughts waft toward the old cliché: Think outside the box. I’ve always hated when people say that.

To begin with, the directions are ineffectual. You can’t tell someone to think outside the box and expect them to do it. Creativity doesn’t happen on demand. Want proof? Just try to make yourself think a brilliant thought, something original, innovative, or unique. Go ahead. Do it. Right now. You can’t, no matter how hard you try.

Therefore, no matter how many people tell me to think outside the box, I won’t do it. I can’t. Even if I could, I’m not sure it would be worthwhile. Consider the origins of the phrase. It started with an old brain

teaser. Nine dots are in a perfect square, lined up three by three. Connect them all, using only four straight lines, without lifting your pencil from the paper. The solution involves letting the lines expand out onto the empty page, into the negative space. You need to recognize that the field is wider than you’d assume. In other words, don’t interpret the dots as a square, don’t imagine that the space is constricted. Think outside the box!

An idea can’t stand on its own; it needs a structure and a foundation.

Studies have found that solving the nine-dot problem has nothing to do with the box. Even when test subjects were told that the solution requires going outside the square’s boundaries, most of them still couldn’t solve it. The puzzle is just difficult, no matter which side of the box you’re standing on.

Still, I bet my 12-year-old son could solve it. Yesterday, we unpacked a set of oil paints, delivered in the mail. He was admiring the brushes and canvases. He was thinking about his project, trying to be creative, searching for insight. “Think inside the outside of the box,” he said. “Like with cardboard, you know, with all the little holes inside.”

He was talking about the corrugations, those ridges that are pasted between layers of fiberboard. It doesn’t take an engineering degree to understand how it works: The flutes provide support; the empty space in between makes it lightweight. My son is right; it’s all about what’s inside the outside of the box.

Now I can’t stop saying it to myself, “Think inside the outside of the box.” It’s a perfect little metaphor. In a way, it even sums up the primary cognitive skill I acquired in graduate school. Consider how corrugation gives cardboard its structural integrity. The empty space—what’s not there—makes it strong and light enough that it’s a useful and efficient way to carry objects. Similarly, it’s the intellectual frameworks that make our interpretations and analyses of the world hold up. An idea can’t stand on its own; it needs a structure and a foundation. It requires a frame. And by looking at how those frames are assembled, we’re able to do our best thinking. We look at the empty spaces—the invisible, or tacit assumptions—which lurk within the fluted folds of every intellectual construction. We recognize that our conscious understanding of lived experience is corrugated just like cardboard.

The famous sociologist Erving Goffman said as much in 1974 when he published his essay on “Frame Analysis.” He encouraged his readers to identify the principles of organization which govern our perceptions. It’s why we now talk often about the ways in which folks “frame the conversation.” But I doubt my son has read Goffman. He just stumbled on a beautifully succinct way to frame the concept of critical thinking. Maybe he was inspired by Dr. Seuss.

When my kids were little, they asked for the same story every night: “Read Sneetches, Daddy!” It’s an us-versus-them story, a fable about the way a consumption economy encourages people to compete for status, and to alienate the “other.” If you think inside the outside of the box, it’s also a scathing criticism of a culture that’s



obsessed with personal and professional transformation—always reinventing and rebranding.

Even before the novel coronavirus, a new global paradigm forced us to live and work in a world that’s organized according to a geopolitical model we can barely comprehend. High-speed transportation disrupted how we perceive the limits of time and space. Automation upset the criteria through which we understand meritocracy and self-worth. Algorithms and artificial intelligence changed the way we think about labor, employment, and productivity. Data and privacy issues blurred the boundaries of personal sovereignty. And advances in bioengineering shook up the very notion of human nature.

And now, cloistered at home in the midst of a pandemic, our most mundane work-a-day routines are dissolved, making it feel like our core values and deeply-held beliefs are about to tumble out all over the place. We can already envision the mess that is to come—in fact, we’re watching it unfurl in slow motion. Nothing is in its place. Instead, everything is outside the box.

It’s not creative, inspiring, or insightful. No, it’s disorienting and anxiety-provoking. I want to tidy it up as quickly as possible. I want to put things back in their familiar places. I want to restore order and eliminate chaos. But no matter how hard I try, I can’t do it, because the old boxes are ripped and torn. Their bottoms have fallen out. Now, they’re useless. Social, cultural, economic, spiritual, psychological, emotional, intellectual: Everything is outside the box. And this new sheltered-in-place experience won’t fit into old containers.

—Jordan Shapiro

COGNITIVE SCIENCE

The Problem with the Way Scientists Study Reason

LAST YEAR, I WAS IN PARIS for the International Convention of Psychological Science, one of the most prestigious gatherings in cognitive science. I listened to talks from my field, human reasoning, but I also enjoyed those on ethology, because I find studies on non-human animals, from turtles to parrots, fascinating. Despite their typically small sample sizes, I found the scientific reasoning in the animal-studies talks sounder, and their explanations richer, than the work I heard on human reasoning.

The reason is simple: Ethologists evaluate their experimental paradigm, or set-up, in light of its ecological validity, or how well it matches natural surroundings. An animal's true habitat, and its evolutionary history, have always centered the discussion. In contrast, most experimental paradigms in human reasoning, such as the Cognitive Reflexion Test (CRT) or syllogisms, are based on logic or mathematics. One of the most famous tasks of the CRT is the bat and ball problem: A bat and a ball cost \$1.10. The bat costs \$1 more than the ball. How much does the ball cost? Most participants fail at this task. The correct answer is not 10 cents, but 5 cents. Perhaps the ultimate tool psychologists use to study reasoning is the syllogism: For example, "Major premise: All men are animals. Minor premise: Some animals are aggressive. Conclusion: Some men are aggressive." (Does this conclusion follow?)

As I listened to talks relying on these methods, I wondered: Do people think like that in everyday life? Probably not. Did our Pleistocene ancestors? Very unlikely. Then, how should I interpret these results? Is using abstract logic on humans like asking a turtle to climb stairs?

Nikolaas Tinbergen, the founder of behavioral ecology, famously stated that ethology is the art of interviewing animals in their own language. This principle is simple but powerful. And there is no reason why it should not be applied to humans. Psychologists studying reasoning extensively rely on logic and philosophy, and neglect psychology's more natural ally: biology. The neglect stems in part from the ease with which humans



can seem to understand one another. Our psychology is equipped with specialized cognitive systems, like theory of mind, that help us negotiate social life. We spontaneously attribute intentions, reasons, and beliefs to others. These heuristics help us to predict behavior, but they also parasitize our scientific understanding of the mind, blinding us to the necessity of using biology when studying ourselves. With turtles, there's no problem, because we have only weak intuitions about their behaviors, and it's difficult to ask them what they think.

Humans are, in other words, too familiar with one another. Fundamental laws of biology, like evolution by natural selection, are falsely believed to have weak constraints on human psychology—particularly for high-level cognitive functions, like reasoning. But the human brain, just like the turtle brain, has been shaped by millions of years of evolution. Reason is unlikely to have escaped its influence. What does it mean, then, to interview humans in their own language?

It is important, when analyzing a biological mechanism, to consider an animal's evolutionary history—the environment in which its ancestors evolved, and the recurrent problems they had to solve. Four broad questions can be answered: "How does it work?"; "How does it develop?"; "Why does it work like that?"; and "How

did it develop in the course of evolution?” The first two questions offer *proximate* explanations, whereas the two last questions offer *ultimate* explanations.

This logic of reverse engineering, at the heart of evolutionary biology, is rarely applied to reasoning. Instead, scholars attribute the role of correcting one’s intuition and solving problems to reasoning. This role is often left implicit because it’s rarely considered an object worthy of scientific discussion. In fact, it has long been a black box that very few have had the courage to open with the adequate biological tools.

Hugo Mercier, who I work with at École Normale Supérieure, and Dan Sperber ventured there in their 2017 book, *The Enigma of Reason*. According to them, reasoning is not a capacity to correct false intuitions or solve problems. Nature is full of problems that organisms have to solve (like finding a mate, or food for dinner) and they constantly update their priors, or beliefs, about their environment in a broadly rational fashion.

Mercier and Sperber say that reason is a tool that evolved to solve particular problems related to communication, like evaluating information provided by others, convincing family or tribe members with arguments, and justifying one’s behavior to protect and improve one’s reputation in a complex social world.

Humans are, in other words,
too familiar with one another.

Their theory makes novel and testable hypotheses, like that reason works best when people argue with each other rather than reason alone, and that we evaluate arguments more objectively than we make them.

In light of their theory, the failure and success of reasoning tasks makes more sense. For example, alone, we are mediocre at solving the bat and ball problem, but in a more ecological setting, when we can argue and reason collectively, the right answer spreads like wildfire.

Instead of trying hard to find biases in human cognition using weird tasks with little ecological validity, the psychology of reasoning would be more productive if more researchers follow Tinbergen’s simple lesson: Interview animals in their own language. Otherwise, we might be lost in translation for a while.

—Sacha Altay

PSYCHOLOGY

Scientists Can Predict Your Job by Your Tweets

FINDING THE “RIGHT” CAREER can feel like an impossible feat. When my little sister was in her last year of high school, she took a career aptitude test. Her top career? Chimney sweep. Luckily, things look to be working out for my sister. She’s now training to become an engineer, but who knows whether she’ll move on to something else: The average person today will hold about 12 jobs in their lifetime. At any given moment, one in three employees are underqualified for their current roles, while one in four are overqualified. Globally, the vast majority of people feel disengaged at work. Winding up in the wrong profession seems to be a surprisingly common experience.



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While career tests can help, they're no magic bullet. Most rely on self-report surveys, which are not only time consuming, but can be faked. It's also debatable whether the results from these tests are meaningful. A new paper offers an alternative to the imperfect career test: the Twitter feed. The researchers applied machine-learning approaches to Twitter data to offer what they describe as a "21st-century approach to matching one's personality with congruent occupations." Marian-Andrei Rizoïu, one of the study's co-authors, said, "The study was pretty fascinating because it took this big data approach to personality and career."

Rizoïu and his colleagues analyzed tweets from almost 130,000 Twitter users. By identifying patterns in users' language, the researchers were able to capture what Rizoïu calls personality profiles—collections of traits and values that form who we are. He and his colleagues compared these profiles to the careers that users mentioned in their Twitter bios. The link was strong—so strong that the personality profiles could be used to "predict" professions with more than 70 percent accuracy.

The study could have exciting implications for future job seekers. Peggy Kern, the lead author of the study said, "My hope is that it would allow people to explore more and think about going beyond the typical way that we make [career] decisions."

To recommend occupations, Kern and her colleagues' method relied on two aspects of user

personalities: traits and values. Traits, she explained, are common characteristics like extraversion or neuroticism. Values, on the other hand, represent what we truly care about, like helping others, respecting tradition, or achieving success. Both are core aspects of our personality, and both, it turns out, are deeply linked to how we feel and perform in our careers.

Past studies have connected personality to everything from hireability and career potential to job performance and professional success. Your job-personality fit can even affect your income. In a 2017 study of almost 8,500 employees, people whose personalities were well-suited to their professions were likely to earn up to 10 percent more.

Kern believes that a refined version of the method used in the study could be developed to help people identify career options that truly fit their traits and values, based on the digital traces that they leave through their online behaviors.

Using big data—like this study's large collection of tweets—can be helpful for uncovering trends that would otherwise be difficult to identify. But the method also relies heavily on the status quo, for better or for worse. "I think the paper makes perfect use of the social media data we have available, where you have a massive data set of people's personalities in different locations," said Kiki Leutner, a business psychologist and data scientist who was not involved in the study. "But, of course, you can only look at the current state of things. You can see where extroverted people are more likely to work, but it's unclear whether that means that extroverted people are better in those roles. It doesn't necessarily mean that people's vocational choices are right."

It's not clear whether there are meaningful differences in how diverse groups of Twitter users communicate on the platform—and whether that would affect the career options they're recommended. But if demographics like race, gender, or age do play a role, then machine-learning approaches like the one Kern and her colleagues used could end up perpetuating existing biases in the workplace. "One of the biggest concerns I have is about how it could be misused," she said. "I could very easily imagine some businesses taking it [as] a new way to screen for employees ... I think that would be quite dangerous."

—Alice Fleerackers



We Are the Environment

*We either act in concert with nature,
or nature takes life away*

BY KEVIN BERGER

ILLUSTRATIONS BY JORGE COLOMBO



THE MARQUEE ON MY CLOSED NEIGHBORHOOD movie theater reads, “See you on the other side.” I like reading it every day as I pass by on my walk. It causes me to envision life after the coronavirus pandemic. Which is awfully hard to envision now. But it’s out there. When you have a disease and are in a hospital, alone and afraid, intravenous tubes and sensor wires snaking from your body into digital monitors, all you want is to be normal again. You want nothing more than to have a beer in a dusky bar and read a book in amber light. At least that’s all I wanted last year when I was in a hospital, not from a coronavirus. When, this February, I had that beer in a bar with my book, I was profoundly happy. The worst can pass.



FLYING LESSON Bats don't die from the same coronavirus that kills humans because the bat's anatomy fights the virus to a draw, neutralizing its lethal moves. What's the deal with the human immune system? We don't fly.



With faith, you can ask how life will be on the other side. Will you be changed personally? Will we be changed collectively? The knowledge we're gaining now is making us different people. Pain demands relief, demands we don't repeat what produced it. Will the pain of this pandemic point a new way forward? It hasn't before, as every war attests. This time may be no different. But the pandemic has slipped a piece of knowledge into the body public that may not be easy to repress. It's an insight scientists and poets have voiced for centuries. We're not apart from nature, we are nature. The environment is not outside us, it is us. We either act in concert with the environment that gives us life, or the environment takes life away.

Nothing could better emphasize our union with nature than the lethal coronavirus. It's crafted by a molecule that's been omnipresent on Earth for 4 billion years. Ribonucleic acid may not be the first bridge from geochemical to biochemical life, as some scientists have stated. But it's a catalyst of biological life. It wrote the book on replication, a mechanism for life to evolve by natural selection. RNA's signature molecules, nucleotides, code other molecules, proteins, the building blocks of organisms. When RNA's more chemically stable kin, DNA, arrived on the scene, it outcompeted its ancestor. Primitive organisms assembled into cells and DNA set up shop in their nucleus. It employed its nucleotides to code proteins to compose every tissue in every multicellular species, including us. A shameless opportunist, RNA made itself indispensable in the cellular factory, shuttling information from DNA into the cell's power plant, where proteins are synthesized.



RNA and DNA had other jobs. They could be stripped down to their nucleotides, which encode a sticky protein shell. That gave them the ability to infiltrate any and all species, hijack their reproductive machinery, and propagate in ways that make rabbits look celibate. These freeloading parasites have a name: virus. But viruses are not just destroyers. They wear another evolutionary hat: developers. Viruses “may have originated the DNA replication system of all three cellular domains (archaea, bacteria, eukarya),” writes Luis P. Villarreal, founding director of the Center for Virus Research at the University of California, Irvine.¹ Their role in nature is so successful that DNA and RNA viruses make up the most abundant biological entities on our planet. More viruses on Earth than stars in the universe, scientists like to say.

Today more RNA than DNA viruses thrive in cells like ours, suggesting how ruthless they’ve remained. RNA viruses generally reproduce faster than DNA viruses, in part because they don’t haul around an extra gene to proofread their molecular merger with others’ DNA. So when the reckless RNA virus finds a new place to dwell, organisms become heartbreak hotels. Once inside a cell, the RNA virus slams the door on the chemical saviors dispatched by cells’ immunity sensors. It hijacks DNA’s replicative powers and fans out by the millions, upending cumulative cellular functions. Like the ability to breathe.

HUMANS. WE LOVE METAPHORS. They allow us to compare something as complex as viral infection to something as familiar as an Elvis Presley hit. But metaphors for natural processes are seldom accurate. The language is too porous, inviting our anthropomorphic minds to close the gaps. We imagine viruses have an agenda, are driven by an impetus to search and destroy. But nature doesn’t act with intention. It just acts. A virus lives in a cell like a planet revolves around a sun.

Biologists debate whether a virus should be classified as living because it’s a deadbeat on its own; it only comes to life in others. But that assumes an organism is alive apart from its environment. The biochemist and writer Nick Lane points out, “Viruses use their immediate environment to make copies of themselves. But then so do we: We eat other animals or plants, and we breathe in oxygen. Cut us off from our environment, say with a plastic bag over the head, and we die in a few minutes. One could say that we parasitize our environment—like viruses.”²

Guess which species is the bully? No animal has had the capacity to modify its niche the way we have.



BOOK OF GENESIS Ribonucleic acid may not be the first bridge from geochemical to biochemical life, as some scientists have stated. But RNA is a catalyst of biological life. It wrote the book on replication, a mechanism for life to evolve by natural selection.

Our inseparable accord with the environment is why the coronavirus is now in us. Its genomic signature is almost a perfect match with a coronavirus that thrives in bats whose habitats range across the globe. Humans moved into the bats' territory and the bats' virus moved into humans. The exchange is just nature doing its thing. "And nature has been doing its thing for 3.75 billion years, when bacteria fought viruses just as we fight them now," says Shahid Naeem, an upbeat professor of ecology at Columbia University, where he is director of the Earth Institute Center for Environmental Sustainability. If we want to assign blame, it lies with our collectively poor understanding of ecology.

Organisms evolve with uniquely adaptive traits. Bats play many ecological roles. They are pollinators, seed-spreaders, and pest-controllers. They don't die from the same coronavirus that kills humans because the bat's anatomy fights the virus to a draw, neutralizing its lethal moves. What's the deal with the human immune system? We don't fly. "Bats are flying mammals, which is very unusual," says Christine K. Johnson, an epidemiologist at the One Health Institute at the University of California, Davis, who studies virus spillover from animals to humans. "They get very high temperatures when they fly, and have evolved immunological features, which humans haven't, to accommodate those temperatures."

A viral invasion can overstimulate the chemical responses from a mammal's immune system to the point where the response itself causes excessive inflammation in tissues. A small protein called a cytokine, which orchestrates cellular responses to foreign invaders, can get over-excited by an aggressive RNA virus, and erupt into a "storm" that destroys normal cellular function—a process physicians have documented in many current coronavirus fatalities. Bats have genetic mechanisms to inhibit that overreaction. Similarly, bat flight requires an increased rate of metabolism. Their wing-flapping action leads to high levels of oxygen-free radicals—a natural byproduct of metabolism—that can damage DNA. As a result, states a 2019 study in the journal *Viruses*, "bats probably evolved mechanisms to suppress activation of immune response due to damaged DNA generated via flight, thereby leading to reduced inflammation."³

Bats don't have better immune systems than humans; just different. Our immune systems evolved for many things, just not flying. Humans do well around the cave fungus *Pseudogymnoascus destructans*, source of the "white-nose syndrome" that has devastated bats worldwide. Trouble begins when we barge into wildlife

habitats with no respect for differences. (Trouble for us and other animals. White-nose syndrome spread in part on cavers' shoes and clothing, who tracked it from one site to the next.) We mine for gold, develop housing tracts, and plow forests into feedlots. We make other animals' habitats our own.

Nature has been doing its thing for 3.75 billion years, when bacteria fought viruses as we fight them now.

OUR MORALISTIC BRAIN sees retribution. Karma. A viral outbreak is the wrath that nature heaps on us for bulldozing animals out of their homes. Not so. "We didn't violate any evolutionary or ecological laws because nature doesn't care what we do," Naeem says. Making over the world for ourselves is just humans being the animals we are. "Every species, if they had the upper hand, would transform the world into what it wants," Naeem says. "Birds build nests, bees build hives, beavers build dams. It's called niche construction. If domestic cats ruled the world, they would make the world in their image. It would be full of litter trays, lots of birds, lots of mice, and lots of fish."

But nature isn't an idyllic land of animal villages constructed by evolution. Species' niche-building ways have always brought them into contact with each other. "Nature is ruled by processes like competition, predation, and mutualism," Naeem says. "Some of them are positive, some are negative, some are neutral. That





goes for our interactions with the microbial world, including viruses, which range from super beneficial to super harmful.”

Ultimately, nature works out a truce. “If the flower tries to short the hummingbird on sugar, the hummingbird is not going to provide it with pollination,” Naeem says. “If the hummingbird sucks up all the nectar and doesn’t do pollination well, it’s going to get pinged as well. Through this kind of back and forth, species hammer out an optimal way of getting along in nature. Evolution winds up finding some middle ground.” Naeem pauses. “If you try to beat up everybody, though, it’s not going to work.”

Guess which species is the bully? “There’s never been any species on this planet in its entire history that has had the capacity to modify its niche the way we have,” Naeem says. Our niche—cities, farms, factories—has made the planet into a zoological Manhattan. Living in close proximity with other species, and their viruses, means we are going to rub shoulders with them. Dense living isn’t for everyone. But a global economy is. And with it comes an intercontinental transportation system. A virus doesn’t have a nationality. It can travel as easily from Arkansas to China as the other way around. A pandemic is an inevitable outcome of our modified niche.

Although nature doesn’t do retribution, our clashes with it have mutual consequences. The exact route of transmission of SARS-CoV-2 from bat to humans remains unmapped. Did the virus pass directly into a person, who may have handled a bat, or through an intermediate animal? What is clear is the first step, which is that a bat shed the virus in some way. University of California, Davis epidemiologist Johnson explains bats shed viruses in their urine, feces, and saliva. They might urinate on fruit or eat a piece of it, and then discard it on the ground, where an animal may eat it. The Nipah virus outbreak in 1999 was spurred by a bat that left behind a piece of fruit that came in contact with a domestic pig and humans. The Ebola outbreaks in the early 2000s in Central Africa likely began when an ape, who became bushmeat for humans, came in contact with a fruit bat’s leftover. “The same thing happened with the Hendra virus in Australia in 1994,” says Johnson. “Horses got infected because fruit bats lived in trees near the horse farm. Domesticated species are often an intermediary between bats and humans, and they amplify the outbreak before it gets to humans.”

Our moralistic brain sees a viral outbreak as nature’s retribution. Karma. It’s not so.

Transforming bat niches into our own sends bats scattering—right into our backyards. In a study released in April, Johnson and colleagues show the spillover risk of viruses is the highest among animal species, notably bats, that have expanded their range, due to urbanization and crop production, into human-run landscapes.⁴ “The ways we’ve altered the landscape have brought a lot of great things to people,” Johnson says. “But that has put wildlife at higher pressures to adapt, and some of them have adapted by moving in with us.”

Pressures on bats have another consequence. Studies indicate physiological and environmental stress can increase viral replication in them and cause them to shed more than they normally do. One study showed bats with white-nose syndrome had “60 times more coronavirus in their intestines” as uninfected bats.⁵ Despite evidence for an increase in viral replication and shedding in stressed bats, “a direct link to spillover has yet to be established,” concludes a 2019 report in *Viruses*.³ But it’s safe to say that bats being perpetually driven from their caves into our barns is not ideal for either species.

AS MY QUESTIONS RAN OUT for Columbia University’s Naeem, I asked him to put this horrible pandemic in a final ecological light for me.

“We think of ourselves as being resilient and robust, but it takes something like this to realize we’re still a biological entity that’s not capable of totally controlling the world around us,” he says. “Our social system has become so disconnected from nature that we no longer understand we still are a part of it. Breathable air, potable water, productive fields, a stable environment—these all come about because we’re part of this elaborate system, the biosphere. Now we’re suffering environmental consequences like climate change and the loss of food security and viral outbreaks because we’ve forgotten how to integrate our endeavors with nature.”

A 2014 study by a host of wildlife ecologists, economists, and evolutionary biologists lays out a plan to stem the tide of emergent infectious diseases, most of which spawned in wildlife. Cases of emergent infectious diseases have practically quadrupled since 1940.⁶ World leaders could get smart. They could pool money for spillover research, which would identify the hundreds of thousands of potentially lethal viruses in animals. They could coordinate pandemic preparation with international health regulations. They could support animal conservation with barriers that developers can’t cross. The scientists give us 27 years to cut the rise of infectious diseases by 50 percent.



After that, the study doesn't say what the world will look like. I imagine it will look like a New York City hospital in April.

Patients lie on gurneys in corridors, swaddled in sheets, their faces shrouded by respirators. They're surrounded by doctors and nurses desperately trying to revive them. In pain, inconsolable, and alone. I know they want nothing more than to see their family and friends on the other side, to be wheeled out of the hospital and feel normal again. Will they? Will others in the future? It will take tremendous political will to avoid the next pandemic. And it must begin with a reckoning with our relationship with nature. That tiny necklace of RNA tearing through patients' lungs right now is the world we live in. And have always lived in. We can't be cut off from the environment. When I see the suffering in hospitals, I can only ask, Do we get it now? 🌀

KEVIN BERGER is the editor of *Nautilus*.

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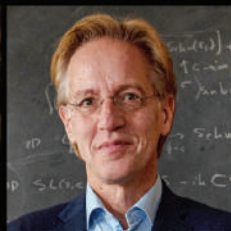
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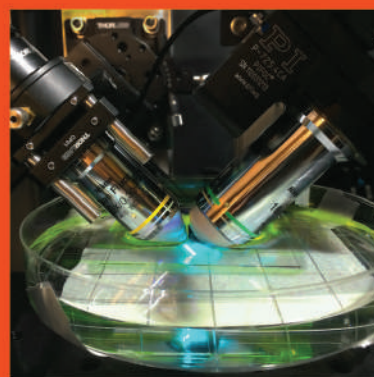
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The Unintended Beauty of Starlings

Those wondrous, undulating flocks are stirred by predators

BY MARK MACNAMARA

EUGENE SCHIEFFELIN WAS the eccentric ornithologist who in 1890 shipped 60 starlings from London to New York City and set them free in Central Park. The next year he released 40 more, and today there are maybe 200 million starlings in the United States and Southern Canada. As immigrants go, starlings are shrewd flyers, clever mimics, and often unwelcome. The truth is they're no more than uptown blackbirds, stocky, three-ounce grifters with iridescent blue and green plumage, along with yellow beaks and a long history of displacing woodpeckers and flycatchers, and destroying entire crops of berries and cherries. Not to mention the havoc they cause at many airports.

COATESY / SHUTTERSTOCK

Ah, but when they come round in their murmurations on fall afternoons, or in early winter, what magicianry is that, gathering up out of nowhere, arriving in strands or massive clusters, over inlets or forests. You'll see them fill up neighboring trees and fall into an oily, high-pitched chatter. Sooner or later, they settle and fall silent, like an orchestra before the first note. And then—the most subtle spooking will do it, a dog's bark, the slam of a car door down the street, or nothing at all, and off they go at 50 miles per hour, wheeling around the countryside, sheets and sheets of them, thickening and thinning, blackening and scattering, merging and splitting, sometimes looking like a tornado cloud, or else some strange omen, and it'll go on for 15 minutes or more, a merry band thrashing through the sky in vast clouds of star-shaped dots, like the vanishing images on a Buddha board.

The word murmuration is derived from the murmuring sound of beating wings. The performance is self-organized, cohesive, and perfectly synchronized; and distinguished by elaborate patterns of spirals, spheres, planes, and waves. What causes starlings to perform these displays? And what do they reveal about the nature of collective behavior in animals?

Theories have evolved over the last century. In 1931, Edmund Selous, a renowned ornithologist and bird activist—his older brother was the famous big game hunter Frederick Selous—wrote a book called *Thought-Transference (or What?) in Birds*. The notion was that birds in a flock must all be “thinking” as one; how else to explain the synchronization except by telepathy. But Selous had no evidence, only a layman's logic. *Nature* panned the book and that was the end of it.

Later theories suggested that murmurations are ways to find food and keep warm. Those theories linger, but in the past 50 years the predominant explanation is predation, particularly the role of raptors, such as hawks and falcons, in triggering escape behaviors that involve particular patterns of grouping. These behaviors are also found in gulls, dunlins, and corvids. The main benefit of flocking is making it difficult for predators to single out prey.

In the mid 1960s, researchers found that murmuring birds, particularly starlings, interact—not always, but often—with six or seven of their closest neighbors, who interact with six or seven of their closest

neighbors. In recent years, studies posit that a network with seven neighbors optimizes the trade-off between “group cohesion and individual effort.” One theory among researchers, in the context of predation, is that starlings are “managing uncertainty while maintaining consensus.”¹ Which is to say they must fly a fine line between reacting solely to the falcon or staying within the fortress of the flock. Either way is fraught. Thus, the need to manage uncertainty.

It's evolution in the skies, the prey adopting a strategy to outsmart the predator.

In a murmuration, the distance between fellow fliers is based on a set of rules also seen in certain kinds of fish and insects. These rules require birds to draw closer to birds farther away; at the same time, not to get too close to the nearest neighbor; and finally to join in directional flow. Add to these rules the aerodynamic factors in starlings—and the blistering speed at which the birds turn, climb, and dive—and you have a sense of the intricacy of flock synchronization.

Mario Pesendorfer, a postdoctoral research associate at the University of Natural Resources and Life Sciences in Vienna, whose work often focuses on birds, cautions about ascribing behavior to inborn patterns in animals' brains. “When humans observe a complex global (group) pattern that arises from simple behavioral rules on the level of individuals,” he tells me in an email, “we are not very good at deciphering the individual rules. Instead, we ascribe intention, as well as other complex cognitive and behavioral processes to the animals.”



AERIAL DEFENSE When a predator, like the hawk seen here, swoops into a flock, the starlings often zig and zag in formation, creating darkened bands that confound the predator, preventing it from singling out a bird.

In 2019, evolutionary biologist Rolf F. Storms at the Groningen Institute for Evolutionary Life Sciences in the Netherlands, led a study on starlings that delved into the rules of murmurations.² Storms' interest has always been in self-organization, "where complex phenomena can be explained through the entities in the system interacting with each other through simple rules," he tells me in an email. "That simple rules can give rise to such complexity fascinated me. I would say the most mesmerizing examples can be seen in the murmurations of starlings."

The study, which was conducted in Rome and analyzed video footage of falcon hunting techniques, found different patterns of escape by the starlings. For example, when a falcon attacked a flock from above—not from the sides or below, and at high speed—the

starlings frequently respond with an escape pattern called a "flash expansion." The birds scatter in all directions in the sky. "But since flocking offers many benefits," says Storms, "individuals will try to go back to their flock mates as soon as the immediate threat of being caught has lowered, which would explain the resilience of the flock against being split." When a falcon attacks starlings at medium speed, allowing it to be detected, warnings spread through the flock, and the birds respond in a "wave." They turn right and left, zig and zag, creating "darkened bands" that ripple through the flock, confusing the falcon. This aerial display exhibits the kind of collective intelligence that scientists see in other species, in which individuals join together to solve a single problem, in this case avoiding a hungry falcon.

SERKAN MUTAN / SHUTTERSTOCK

Grainger Hunt, Senior Scientist Emeritus with the Peregrine Fund's California Condor and Aplomado Falcon restoration project, underscores the fact that murmurations are emergent. "We are accustomed to seeing organized aggregations, such as groups of musicians, dancers, or soldiers, that behave as if they were purposeful units," Hunt tells me. "The explanation is that they are directed, either by prior arrangement or by a conductor. It might likewise seem that the peregrine conducts the starling flock for the purpose of producing the effects we see from afar. But the peregrine does not purpose the shapes and movements of the flock. Nor does any starling. The spectacle of wondrous shapes and movements is an unintended effect. The peregrine is trying to catch a starling, and each starling is trying not to get caught."

It's evolution in the skies, the prey adopting a strategy to outsmart the predator. This unintended big dazzle is also a reminder that, often, nature's most beautiful offerings are inspired by desperation and danger. 🌀

MARK MACNAMARA is an Asheville, North Carolina-based writer. His articles for *Nautilus* include "We Need to Talk About Peat" and "The Artist of the Unbreakable Code."

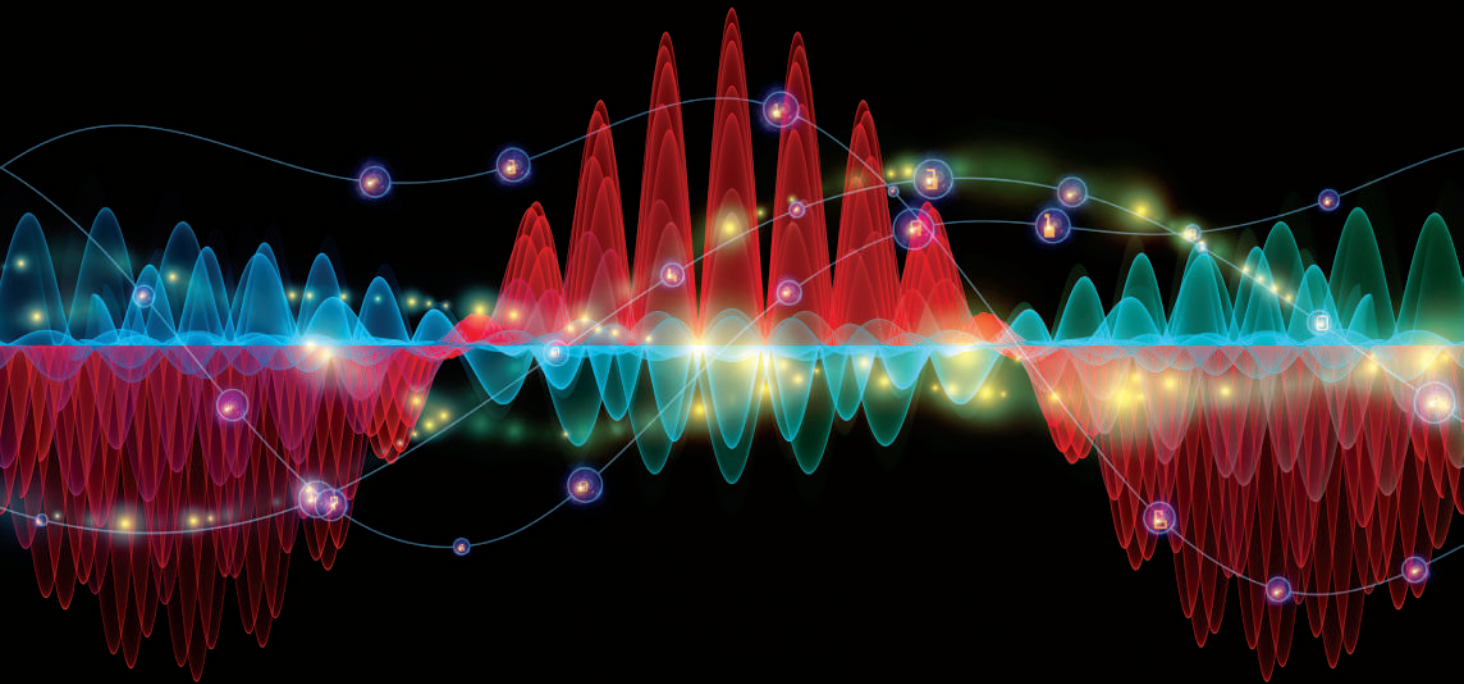
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How to Make Sense of Quantum Physics

Superdeterminism, a long-abandoned idea, may help us overcome the current crisis in physics

BY SABINE HOSSENFELDER & TIM PALMER



QUANTUM MECHANICS ISN'T ROCKET SCIENCE. But it's well on the way to take the place of rocket science as the go-to metaphor for unintelligible math. Quantum mechanics, you have certainly heard, is infamously difficult to understand. It defies intuition. It makes no sense. Popular science accounts inevitably refer to it as "strange," "weird," "mind-boggling," or all of the above.

We beg to differ. Quantum mechanics is perfectly comprehensible. It's just that physicists abandoned the only way to make sense of it half a century ago. Fast forward to today and progress in the foundations of physics has all but stalled. The big questions that were open then are still open today. We still don't know what dark matter is, we still have not resolved the disagreement between Einstein's theory of gravity and the standard model of particle physics, and we still do not understand how measurements work in quantum mechanics.

How can we overcome this crisis? We think it's about time to revisit a long-forgotten solution, superdeterminism, the idea that no two places in the universe are truly independent of each other. This solution gives us a physical understanding of quantum measurements, and promises to improve quantum theory. Revising quantum theory would be a game changer for physicists' efforts to solve the other problems in their discipline and to find novel applications of quantum technology.

Quantum Mechanics Is Everywhere

Until now, physicists and philosophers likewise took it for granted that it's not quantum mechanics which has shortcomings, but our understanding of it. For this reason, their efforts to make sense of it have focused on reinterpreting its mathematics, hoping that things will click into place eventually. This has not happened and it's not going to happen. That's because the problem with quantum mechanics is not

one of interpretation. The problem is that all existing interpretations of quantum mechanics have internal contradictions and those can only be resolved by a better theory. Quantum mechanics cannot be how nature works on the most fundamental level; we have to move beyond it.

In all fairness, complaining about the shortcomings of quantum mechanics and calling for its replacement is quite the worst of insults to hurl at a theory so dramatically successful and accurate. Credit where credit is due, so let us emphasize that—weird or not—quantum mechanics, at now more than 100 years of age, has done the most amazing job, and has more than earned its fellowship of devoted physicists.

Without quantum mechanics, we would not have lasers, would not have semi-conductors and transistors, would not have computers, digital cameras, or touchscreens. We would not have magnetic spin resonance, electron tunnel microscopes, or atomic clocks. Nor would we have any of the countless applications based on all these technologies. We'd have no Wi-Fi, no artificial intelligence, no LEDs, and modern medicine basically wouldn't exist because most imaging tools and analysis methods now rely on quantum mechanics. Last but not least, no one would ever have heard of quantum computers.

There is no doubt, therefore, that quantum mechanics is enormously relevant for society. But for the same reasons, there is no doubt that much could be gained from better understanding it.



HIDDEN VARIABLE The outcome of a dice-throw is unpredictable because it's sensitive to details, like the motion of your hand. Since this is information we don't have, throwing dice is random for all practical purposes. This is how to make sense of quantum mechanics. With missing information, the outcome of a quantum measurement could follow.

Nobody Understands Quantum Mechanics

So why have even prominent physicists repeatedly stated quantum mechanics cannot be understood?

The central ingredient of quantum mechanics are mathematical objects called wave functions. Wave functions describe elementary particles, and since everything is made of elementary particles, wave functions describe everything. So, there's a wave function for electrons, a wave function for atoms, a wave function for cats, and so on. Strictly speaking, everything has quantum behavior, it's just that in daily life most quantum behavior is not observable.

Trouble is, no one knows why quantum effects disappear when one tries to measure them. This “measurement problem” has bugged physicists ever since they thought up quantum mechanics. Parts of the puzzle have meanwhile been solved, but this partial solution is still unsatisfactory.

To see the problem, consider you have a single particle and two detectors, one left, one right. If you send the particle left, the left detector ticks. If you send the particle right, the right detector clicks. So far, so unsurprising. But in quantum mechanics you can do more than that: You can have a particle that is in two states at the same time. You can, for example, send it through a beam-splitter so that afterward it is going both left and right. Physicists say the particle is in a “superposition” of left *and* right.

But you never observe a particle in a superposition of measurement outcomes. For such a superposition, the wave function of the particle will not let you predict what you measure; you can only predict the probability of what you measure. Let's say it predicts 50 percent left and 50 percent right. Such a prediction makes sense for a collection of particles, or for a sequence of repeated measurements, but makes no sense for a single particle. The detector either clicks or it doesn't. There's just isn't such a thing as a 50 percent measurement.

Mathematically, “clicks or doesn't click” requires that we update the wave function at the moment of measurement, so that after measurement the particle is 100 percent in the detector in which it was indeed measured.

This update (aka the “collapse” of the wave function) is instantaneous; it happens at the same time

Quantum mechanics cannot be how nature works on the most fundamental level; we have to move beyond it.

everywhere. It may appear as if this was in conflict with Einstein's speed-of-light limit. However, an observer cannot exploit this to send information faster than light because the observer has no control over what the measurement outcome is.

Indeed, the simultaneity of the measurement update is not the main problem. The main problem is that if quantum mechanics was—as most physicists believe—a theory for elementary particles, then the measurement update should be superfluous. The detector, after all, is also made of elementary particles, so we should be able to calculate what happens in a measurement.

Unfortunately, it is not only that we do not know how to calculate what the detector does when hit by a particle unless we just postulate the update. It is far worse: We know it is not possible.

We know it is not possible to correctly describe a quantum measurement without the update of the wave function, because the measurement process is more complicated than the behavior of the wave function when we do not observe it. The measurement process has the main purpose of removing superpositions of measurable outcomes. An unmeasured wave function, to the contrary, maintains superpositions, which is simply not what we observe. We have never encountered a detector that both clicks and doesn't click.

Formally this means that while quantum mechanics is linear (maintains superpositions) the measurement process is “non-linear”; it belongs to a class of theories more complicated than quantum mechanics. This is an important clue to improve quantum mechanics, but it has gone almost entirely unnoticed.

Instead, physicists have swept the conundrum of quantum measurement under the rug by denying that the wave function even describes single particles. The most widely accepted interpretation of quantum theory has it that the wave function describes not the particle itself, but an observer's knowledge of what the particle

does. This knowledge, reasonably enough, should be updated when we make a measurement. What this knowledge is about, you are not supposed to ask.

This interpretation, however, does not remove the problem that if quantum mechanics was fundamental, then we should be able to calculate what happens during measurement. Talking about “knowledge” held by an “observer” also refers to macroscopic objects whose behavior should be derivable, at least in principle, from the behavior of elementary particles. And again, we already know that this is not possible because the measurement process is not linear. One cannot resolve an inconsistency by reinterpreting the math, only by correcting the math.

The Obvious Solution

There are only two ways out of this conundrum. One is to reject reductionism and accept that some things that large objects do cannot be derived from what their constituents do, not even in principle.

Rejecting reductionism is popular among philosophers, but exceedingly unpopular among scientists, and for good reasons. Reductionism has been remarkably successful and is empirically well-established. Even more importantly, no one has ever proposed a consistent, non-reductionist theory of nature (unless you count verbose pamphlets that are not even wrong). And abandoning reductionism without proposing a better explanation is not only useless, it is outright anti-scientific. It does not help us make progress.

The other logical solution is that quantum mechanics is just not a fundamental theory, and its problems are a glimpse of a deeper layer of reality.

If quantum mechanics is not a fundamental theory, then the reason we cannot predict outcomes of quantum measurements is simply that we lack information. Quantum randomness, then, is no different from the randomness in, say, throwing a dice.

Trouble is, no one knows why quantum effects disappear when one tries to measure them.

The outcome of a dice-throw is predictable in principle. It is unpredictable in practice because it is very sensitive to even the most miniscule details, like the exact motion of your hand, imperfections in the shape of the die, or the roughness of the surface on which it rolls. Since this is information we do not have (or even if we had it, wouldn't be able to calculate with) throwing dice is random for all practical purposes. The best prediction we can make is to say that when we average over the unknown, exact details, the probability of any face coming out up is 1 in 6.

This is how to make sense of quantum mechanics. Measurement results might be predictable in principle. It is just that we are missing information. The wave function, then, would not itself be a description of

a single particle. It would be an average over all the details we are missing. This would explain why quantum mechanics makes only probabilistic predictions. And while the underlying, new theory must reproduce the predictions of quantum mechanics in cases we have tested already, if we had this theory we could also tell in which cases we should see deviations from quantum mechanics.

This idea is supported by the fact that the empirically confirmed equation which determines the behavior of the wave function is almost identical to the equation physicists use to describe the behavior of collections of particles, not single particles.

Historically, this way of making sense of quantum mechanics has been called a "hidden variables theory."

“Hidden variables,” here, is a collective term for all unknown information from which, if we had it, the outcome of a quantum measurement would follow.

These hidden variables, it must be emphasized, are not necessarily properties of the particles themselves. Indeed, the idea that they are is strongly disfavored by experiment already. Viable hidden variables encode missing information in the global configuration of the system. Therefore, while a theory of hidden variables is reductionist in the sense that quantum mechanics can be derived from it, the new physics does not reside on distances so short they must be tested with huge particle accelerators.

How Physics Took the Wrong Path

Let us emphasize that theories with hidden variables are not interpretations of quantum mechanics. They are different theories which describe nature more accurately and can indeed solve, rather than talk away, the measurement problem.

Needless to say, we are not the first to point out that quantum mechanics walks and talks like a theory for averages. This is probably what springs to everybody’s mind when confronted with random measurement outcomes. And hidden variables have been considered by physicists since the early days of quantum mechanics. But then they erroneously concluded the option is not viable, an error that persists today.

The mistake physicists made decades ago was to draw the wrong conclusion from a mathematical theorem proved by John Bell in 1964. This theorem shows that in any theory in which hidden variables let us predict measurement outcomes, the correlations between measurement outcomes obey a bound. Since then, countless experiments have shown that this bound can be violated. It follows that the type of hidden variables theories to which Bell’s Theorem applies are falsified. The conclusion that physicists drew is that quantum theory is correct and hidden variables not.

But Bell’s Theorem makes an assumption which is itself unsupported by evidence: That the hidden variables (whatever they are) are independent of the settings of the detector. This assumption—called “statistical independence”—is reasonable as long as an experiment only involves large objects like pills, mice, or cancer cells. (And indeed, in this case a violation of

Universal relatedness, this idea’s defining feature, does not reveal itself on the level of elementary particles.

Free will, while it tends to ignite furious debate, is entirely tangential to understanding quantum physics.

statistical independence would strongly suggest the experiment had been tampered with.) Whether it holds for quantum particles, however, no one knows. Because of this we can equally well conclude that the experiments which test Bell's Theorem, rather than supporting quantum theory, have proved that statistical independence is violated.

Hidden variables theories that violate statistical independence give superdeterminism its name. Shockingly enough, they have never been ruled out. They have never even been experimentally tested because that would require a different type of experiment than what physicists have done so far. To test superdeterminism, one would have to look for evidence that quantum physics is not as random as we think it is.

The core idea of superdeterminism is that everything in the universe is related to everything else because the laws of nature prohibit certain configurations of particles (or make them so unlikely that for all practical purposes they never occur). If you had an empty universe and placed one particle in it, then you could not place the other ones arbitrarily. They'd have to obey certain relations to the first.

This universal relatedness means in particular that if you want to measure the properties of a quantum particle, then this particle was never independent of the measurement apparatus. This is not because there is any interaction happening between the apparatus and the particle. The dependence between both is simply a property of nature that goes unnoticed if one deals only with large devices. If this was so, quantum measurements had definite outcomes—hence solving the measurement problem—while still giving rise to violations of Bell's bound. Suddenly it all makes sense!

It is difficult to explain why physicists spent half a century with an inconsistent theory but never seriously considered that statistical independence may just be violated. We suspect part of the reason is that the rather technical assumption of statistical independence has become metaphorically related to the free will of the experimenter. Humans are cognitively biased to believe in free will and this bias likely contributed to physicists collectively turning a blind eye on a promising explanation.

The issue of free will has become tied to superdeterminism because it seems that if statistical

independence is violated, the experimenter is not free to choose both the settings of their apparatus and the preparation of the particle to be measured. But free will, while it tends to ignite furious debate, is entirely tangential to understanding quantum physics. Detector settings can be chosen by machines. And violating statistical independence does not mean that the experimenter is somehow prevented from choosing a setting they like. It merely means that their setting is part of the information that determines the measurement outcome.

The real issue is that there has been little careful analysis of what exactly the consequences would be if statistical independence was subtly violated in quantum experiments. As we saw above, any theory that solves the measurement problem must be non-linear, and therefore most likely will give rise to chaotic dynamics. The possibility that small changes have large consequences is one of the hallmarks of chaos, and yet it has been thoroughly neglected in the debate about hidden variables.

Low Risk, High Pay-Off

Given the technological relevance of quantum mechanics, moving beyond it would be a major scientific breakthrough. But because of the historical legacy, researchers who have worked on or presently work on superdeterminism have been either ignored or ridiculed. As a consequence, the idea has remained sorely underdeveloped.

Due to the dearth of research, we have to date no generally applicable theory for superdeterminism. We do have some models that provide a basis for understanding the violation of the Bell inequality, but no formalism remotely as flexible as the existing theory of quantum mechanics. While superdeterminism makes some predictions that are largely model-independent, such that measurement outcomes should be less randomly distributed than in quantum mechanics, it is easy to criticize such predictions because they are not based on a full-blown theory. Experimentalists do not want to even test the idea because they do not take it seriously. But we are unlikely to find evidence of superdeterminism by chance. Universal relatedness, which is this idea's defining feature, does not reveal itself on the level of elementary particles. Therefore, we do not

believe that probing smaller and smaller distances with bigger and bigger particle accelerators will help solve the still-open fundamental questions.

It does not help that most physicists today have been falsely taught the measurement problem has been solved, or erroneously think that hidden variables have been ruled out. If anything is mind-boggling about quantum mechanics, it's that physicists have almost entirely ignored the most obvious way to solve its problems. ☹️

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Why I Built a Dumb Cell Phone with a Rotary Dial

You too can build a phone that feels good to use. Some soldering required.

BY JUSTINE HAUPT

IN 2007, WHEN TOUCHSCREENS first started coming on the scene, I was excited, like everyone. As a lifelong science-fiction fan, they always seemed to me to be the obvious choice for future user interfaces. But, for over a decade, I've been living in what feels like a bad dream. The devices we have now are not what science fiction promised. When you grow up using a personal computer with a keyboard and a mouse, you come to expect precision, and the computers of the future—including smartphones—should only be an improvement on that.

In *Star Trek: The Next Generation*, all the computers are touchscreens, cluttered with detail in a good way. The creators of that show imagined what the next step would be beyond the incredibly dexterous control personal computers offered. The crew of the Enterprise weren't poking at big, colorful blocks with context-dependent responses to swipes, with even the most basic functionalities hidden within menus. Most importantly, the computers were used for "computery" things. Mapping the stars. Translating alien languages. Analyzing genomes. There was no hint of social media, or that people would stop talking in favor of the apparently irresistible siren call of texting for even the briefest of correspondence. Or that the technology would be used by our governments to track us.

It was an odd time for me, when touchscreens were rolling out, as I was just coming to terms with the realization that my childhood dream of becoming an airline pilot wasn't what I wanted. I was torn between physics, filmmaking, teaching violin, and a newly sprouted idea of starting an "invention factory" company. Just a few years later, I joined the Cosmology Instrumentation Group at Brookhaven National Laboratory, falling into work on astronomical telescopes, which seemed a bizarre turn of fate since I had no credentials to justify such a position. By this time I'd been exposed to others' smartphones and decided to hold my flip phone close, eventually coming to regard touchscreen technology as generally horrible. Although they're capable

of precision, touchscreen operating systems discard any pretense of maintaining the operational clarity of personal computers. What if I open a program (an Internet-browsing "app," say), swipe it away, and then open it again? If that program is already running, the system will bring that program to the front again—but shouldn't I know whether it's maximizing an already-opened program, or starting it anew? And what if I want to open a second instance of that program instead? These operating systems treat us like we're children, and I don't appreciate it.

This is why, in a sort of rebellion, I've designed and built my own dumb cell phone, complete with a rotary dial. In the last month or so since *Wired* interviewed me, I've been getting so many requests from people wanting to buy the dumbphone that I've decided to make it available in a minimal kit form. Some soldering is required.

With the exception of a roughly month-long experiment with a smartphone, I have been happy with having a flip phone, a good excuse not to text, because everyone knows how awkward and cumbersome texting on one can be. They're not immune to stupid user-interface design either—mine has more than once entered speakerphone mode unprovoked while answering calls, and that kind of thing can cause permanent hearing loss. Nevertheless, to me, the frustrations of smartphones are even more intense. I guess what it comes down to is that I always expected that a future with



BACK TO BASICS Why opt for a rotary cell phone? “Because in a finicky, annoying, touchscreen world of hyperconnected people using phones they have no control over or understanding of,” Justine Haupt says, “I wanted something that would be entirely mine, personal, and absolutely tactile, while also giving me an excuse for not texting.”

Perhaps smart technology can eventually live up to what I saw on TV in the '90s.

pervasive computer technology would beget technologically-inclined users. Instead, the technology has been perverted to *encourage* technical complacency. I began plotting my escape.

The big surprise is that other people actually like the rotary cell phone. I never intended it to be something anyone but myself would use. But it went viral in early February and now, after three years of trying to start the “invention factory” company I envisioned a decade ago—and with the first such product produced and ready to send out to customers (98 of the 100 made are sitting in my basement)—I find myself inundated with emails from people wanting their own rotary cell phone: Wrong product, people!

It’s okay. I’d been itching for years to use a rotary dial as a data entry interface for one of my projects. They’re easy to interface with electrically, so I imagined a rotary numpad replacement for a computer, or perhaps as a means to enter sky coordinates on a steampunk telescope mount. Then, skimming one of my favorite parts suppliers, I noticed a cellular transceiver evaluation board. With that key piece, the possibility of building a cell phone now seemed almost easy, and adding a rotary dial sounded quirky enough to be fun. I could finally have a phone, I thought, that is entirely mine, as tactile as I can imagine—one that behaves the way I want it to (and with no need to write the firmware necessary for texting!). It would be wacky, sure, but that wouldn’t be the point. The point would be to have a real, usable phone, one as far from having a touchscreen as possible while being a slap in the face to smartphones because, in a few ways, it would actually be more functional.

For example, the rotary cell phone—which is now, in fact, my primary phone—has a real external antenna with superior reception; instantaneous signal strength and battery metering with more resolution than just four or five bars; and, on the back, an ePaper display (a

COURTESY OF JUSTINE HAUP

These operating systems treat us like we're children, and I don't appreciate it.

terribly underused and absolutely beautiful technology that's bistatic, meaning it doesn't take energy to display a fixed message, like that you missed a call). The power control is an actual slide switch, not a button you hold down that makes you wonder what it might really be doing. It fits in a pocket. Calling the people I most often call is actually faster than with my old flip phone, and the battery lasts more than a day. Most importantly, if I want to change something about the phone's behavior, I can do it, with no one to blame for poor performance but myself.

A week after the phone garnered more attention than I thought possible, I found myself questioning the wisdom of shunning offers from folks willing to pay obscenely for their own version. I had to seriously consider turning it into a product, and fast. Do you ever write yourself a note that would be both illegible and cryptic to anyone else, but it's okay because you're the only one who ever needs to read it? That's what this phone was for me. It's easy to make a user interface for oneself but it wasn't even close to being something other people could make sense of.

From the original proof of concept, splayed like some unholy vivisection on my workbench, to the more refined device, the functionality of the keys, and the overall form of the casing, has gone through something like five complete rehashings. I had decided, early on, to design a proper printed circuit board instead of doing everything totally by hand, and by the time the phone went viral things were even a bit more polished due to my own obsessiveness. Couple this with the fact that I'd recently cut my teeth understanding how to mass produce electronics, and I was able to come up with a more refined version of the electrical design that could

be mass produced as a kit in about a week. At the time of this writing, several weeks later, I'm still waiting for the first shipment of fully assembled electronics from China.

The only catch is the 3-D-printed enclosures, which comprise the part of the device that the user actually holds and interacts with. However much the media may hype 3-D printing, those of us using the technology know that it's no replacement for injection molding. Luckily, as part of my ongoing and previously faltering attempts to start a company, I'd spent a couple years building a large format (refrigerator-sized) 3-D printer in my basement, which can print four things in parallel for low-volume production. Perhaps this is why engineers don't usually make good CEOs ... the technical challenges of product development, and the associated inclination to make refinements ad infinitum, are far more tempting than business development, with the added pitfall that the engineer will also see the engineering problems as important from a business perspective.

The fact that an actual company with money flowing in and out has come out of this sensation, nearly overnight, highlights that there must be some widely recognized problem with smartphones today. People seem to be dissatisfied with our hyperconnected culture, with its constant notifications, addictive immersiveness, and the demand that we sacrifice our privacy for no technological reason. They're certainly willing to entertain that another way of relating to mobile communications devices is possible. Perhaps we can fix this. Perhaps smart technology can eventually live up to what I saw on TV in the '90s. Perhaps it's not too late. ☺

JUSTINE HAUPT is a developer of astronomy instrumentation at Brookhaven National Laboratory and director of radio astronomy at Custer Observatory in Southold, NY. She is currently working on a radio telescope for dark energy cosmology, and has started an "invention factory" company called Sky's Edge, which designs and produces open-source hardware.

Friendship Is a Lifesaver

Science is showing us the best remedy for aging is friends

BY LYDIA DENWORTH





MY MOTHER-IN-LAW, CAROL, lives alone. It was her 75th birthday the other day. Normally, I send flowers. Normally, she spends some part of the day with the family members who live nearby and not across the country as my husband, Mark, and I do. And normally, she makes plans to celebrate with a friend. But these are not normal times. I was worried about sending a flower delivery person. Social distancing means no visiting with friends or family, no matter how close they are. So, my sister-in-law dropped off a gift and Mark and I sang “Happy Birthday” down the phone line with our kids. But I could hear the loneliness in Carol’s voice.

This was hardly the worst thing anyone experienced in America on that particular April day. We are fortunate that Carol is healthy and safe. But it upset me anyway. People over 60 are more vulnerable to COVID-19 than anyone else. They are also vulnerable to loneliness, especially when they live alone. By forcing us all into social isolation, one public health crisis—the coronavirus—is shining a bright light on another, loneliness. It will be some time before we have a vaccine for the coronavirus. But the antidote to loneliness is accessible to all of us: friendship.

All too often we fail to appreciate what we have until it’s gone. And this shared global moment has illuminated how significant friends are to day-to-day happiness. Science has been accumulating evidence that friendship isn’t just critical for our happiness but our health and longevity. Its presence or absence matters at every point in life, but the cumulative effects of either show up most starkly in the later stages of life. That is also the moment when demographics and health concerns can conspire to make friendships harder to find or sustain. As the world hits pause, it’s worth reminding ourselves why friendship is more important now than ever.

Those who valued friendship as much as family had higher levels of health and happiness.

FRIENDSHIP HAS LONG BEEN UNDERSTOOD to be valuable and pleasurable. Ancient Greek philosophers enjoyed debating its virtues, in the company of friends. But friendship has largely been considered a cultural phenomenon, a pleasant by-product of the human capacity for language and living in groups. In the 1970s and 1980s, a handful of epidemiologists and sociologists began to establish a link between social relationships and health. They showed those who were more socially isolated were more likely to die over the course of the studies. In 2015, a meta-analysis of more than 3 million people whose average age was 66 showed that social isolation and loneliness increased the risk of early mortality by up to 30 percent.¹ Yet loneliness and social isolation are not the same thing. Social isolation is an objective measure of the number and extent of

social contact a person has day to day. Loneliness is a subjective feeling of mismatch between how much social connection you want and how much you have.

Once the link between health and relationships was established in humans, it was noticed in other species as well. Primatologists studying baboons in Africa remarked that when female baboons lost their primary grooming partners to lions or drought, they worked to build bonds with other animals in place of the one they'd lost. When the researchers analyzed the social behavior of the animals and their outcomes over generations, they found in multiple studies that the animals with the strongest social networks live longer and have more and healthier babies than those that are more isolated.² Natural selection has resulted in survival of the friendliest.

Social connection reduces depression, lowers stress, and even slows biological aging.

Since baboons don't drive each other to the hospital, something deeper than social support must be at work. Friendship is getting "under the skin," as biologists say. Some of the mechanisms by which it works have yet to be explained, but studies have demonstrated that social connection improves cardiovascular functioning, reduces susceptibility to inflammation and viral disease, sharpens cognition, reduces depression, lowers stress, and even slows biological aging.³

We also now have a clearer definition of what friendship is. Evolutionary biologists concluded that friendship in monkeys—as well as people—required at least three things: it had to be long-lasting, positive, and cooperative. When an anthropologist looked for consistent definitions of friendship across cultures, he found something similar. Friendships were described

as positive, and they nearly always include a willingness to help, especially in times of crisis. What friendship is about at the end of the day is creating intensely bonded groups that act as protection against life's stresses.⁴

That buffering effect is particularly powerful as we age. Those first epidemiology studies focused on people in the middle of life. In 1987, epidemiologist Teresa Seeman of the University of California, Los Angeles, wondered if age and type of relationship mattered for health.⁵ She found that for those under 60, whether or not they were married mattered most. Being unmarried in midlife put people at greater risk of dying earlier than normal. But that did not turn out to be true for the oldest groups. For those over 60, close ties with friends and relatives mattered more than having a spouse. "That was a real lightbulb that went on," Seeman says.

In a 2016 study, researchers at the University of North Carolina found that in both adolescence and old age, having friends was associated with a lower risk of physiological problems.⁶ The more friends you had, the lower the risk. By contrast, adults in middle age were less affected by variation in how socially connected they were. But the quality of their social relationships—whether friendships provided support or added strain—mattered more. Valuing friendship also proved increasingly important with age in a 2017 study by William Chopik of Michigan State University. He surveyed more than 270,000 adults from 15 to 99 years of age and found that those who valued friendship as much as family had higher levels of health, happiness, and subjective well-being across the lifespan. The effects were especially strong in those over 65. As you get older, friendships become more important, not less; whether you're married is relatively less significant.⁷

THERE'S A WIDESPREAD SENSE, especially among younger people, that people are lonely post-retirement. The truth is more complicated. Social networks do get smaller later in life for a variety of reasons. In retirement, people lose regular interaction with colleagues. Most diseases, and the probability of getting them, worsen with age. It's more likely you will lose a spouse. Friends start to die as well. Mental and physical capacities may diminish, and social lives may be limited by hearing loss or reduced mobility.

What best predicted health wasn't cholesterol levels, but satisfaction in relationships.

Yet some of this social-narrowing is intentional. If time is of the essence, the motivation to derive emotional meaning from life increases, says Laura Carstensen, director of the Stanford Center for Longevity. She found that people choose to spend time with those they really care about. They emphasize quality of relationships over quantity. While family members fill much of a person's inner social circle, friends are there, too, and regularly fill in, in the absence of family. A related, more optimistic perspective on retirement is that with fewer professional and family obligations, there are more hours for the things we want to do and the people with whom we want to do them.

At all stages of life, how we do friendship—whether we focus on one or two close friends or socialize more widely—has to do with our natural levels of sociability and motivation. Those vary, of course. I recently spoke with a man who had retired to Las Vegas. When he and

his wife moved to their new house, his wife began baking cookies and distributing them to neighbors. She started throwing block parties for silly holidays and those neighbors showed up. No one had bothered to organize such a thing before. Even in retirement, this woman is what psychologists call a “social broker”—someone who brings people together. She has most likely always been friendly.

How you live your life before you reach 60 makes a difference, experts on aging say. Friendship is a lifelong endeavor, but not everyone treats it that way. Think of relationships the way we do smoking, says epidemiologist Lisa Berkman of Harvard University. “If you start smoking when you're 14, and stop smoking when you're 65, in many ways, the damage is done,” she says. “It's not undoable. Stopping makes some things better. It's worth doing but it's very late in the game.” Similarly, if you only focus on friendships when your family and professional obligations slow, you will be at a disadvantage. Damage will have been done. The payoff in making friendship a priority was born out in the long-running Harvard Study of Adult Development, which followed more than 700 men for the entire course of their lives. What best predicted how healthy those men were at 80 wasn't middle-aged cholesterol levels, it was how satisfied they were in their relationships at 50.⁸

Fortunately, it is possible to make new friends at every stage of life. In Los Angeles, I met a group of 70-something women who bonded as volunteers for Generation Xchange, an educational and community health nonprofit. The program places older adults in early elementary classrooms as teachers' aids for a school year. As a result of the extra adult attention in class, the children's reading scores have gone up and behavioral problems have gone down. The volunteers' health has improved—they've lost weight, and lowered blood pressure and cholesterol. But they have also become friends, which is just what UCLA's Seeman had in mind when she started the program. “One of the reasons our program may be successful is that we are motivating them to get engaged through their joint interest in helping the kids,” Seeman says. “It takes the pressure off of making friends. You can start getting to know each other in the context of the school and our team. Hopefully, the friendships can grow out of that.”

Concerns about loneliness among the elderly are well-founded. Demographics are not working in favor of the fight against loneliness. By 2035, older adults are projected to outnumber children for the first time in American history. Because of drops in marriage and childbearing, more of those older adults will be unmarried and childless than ever before. The percentage of older adults living alone rose steadily through the 20th century, and now hovers at 27 percent. And a digital divide still exists between older adults and their children and grandchildren, according to recent studies. That means older adults are less able to use virtual technology like Zoom to stay connected during the COVID-19 pandemic—though some are learning. Laura Fisher, a personal trainer in New York City, found that putting her business online meant training older clients one-on-one in videoconferencing. She now works out with one of her young clients in New York City and her client's grandmother in Israel. Generally, older adults who use social media report more support from both their grown children and their friends. "For older people, social media is a real avenue of connection, of relational well-being," says psychologist Jeff Hancock who runs the social media lab at Stanford University.

That is good news in this moment of enforced social isolation. So is the fact that being apart has reminded so many of us of how much we enjoy being together. For my part, I sent those flowers to my mother-in-law after all when I discovered contactless delivery. When the flowers arrived, we spoke again. And then I called her again two days later. "It's great to talk to you," she said. ☺

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Go Tell It on the Mauna

An open letter to telescope protesters in Hawaii

BY DANA MACKENZIE

On July 15, 2019, after a court decision had cleared the way for astronomers to build a new mega-telescope, called the Thirty Meter Telescope, on Hawaii's Mauna Kea, a large group of protesters said, "No." Pitching their camp directly on the access road to the top of Mauna Kea, the protesters, who called themselves *kia'i mauna* (protectors of the mountain), pledged to stop any construction vehicles from passing. The *kia'i* argue that the mountain is sacred to the native Hawaiian people, and that the construction of the TMT would desecrate it.

When I heard about the protest I was torn apart, because I felt forced to choose between my two favorite *ohanas* (families). Though I am not an astronomer, I have been a science writer for 23 years and a mathematician before that, so I am part of the larger science *ohana*. Likewise, I have been a hula dancer for 15 years. Hula is simply a way of telling a story, and men have been part of that folk tradition from the beginning. Dancing with my hula sisters (and occasionally brothers) has taught me to admire the Hawaiian culture, especially their reverence for their land.

The *kia'i* have always said that their complaint is not against science, and I take them at their word. Nevertheless, if you are protesting something it is important to know what you are protesting against. I believe that they have missed one crucial fact about the TMT within the context of Hawaiian culture. The astronomers, likewise, have failed to explain the telescope's value to native Hawaiians in spiritual terms, rather than its value to science or the economy. I hope to bridge that communication gap. In this article I will speak for both of my families, using "we" to mean both astronomers and hula dancers, depending on the context.



AP PHOTO / CALEB JONES

DEAR KIA'I MAUNA,

I greet you in the name of Wakea, the sky god who created the Hawaiian islands and the mountain on which you stand. As you have said many times, Mauna Kea is only a contraction of its full name, Mauna a Wakea—or Wakea's mountain.

For our readers on the mainland, who may not have followed the drama on Mauna Kea closely, I would like to begin by celebrating some of your accomplishments. First and foremost among these, you have introduced the world to the concept of *kapu aloha*. This is a code that requires the protesters to maintain proper (*pono*) and respectful behavior at all times, without anger. Your adherence to this code has prevented any violence aside from the first week, when the police arrested some of your leaders. Your movement follows in the exemplary lineage of Gandhi and Martin Luther King. I consider *kapu aloha* to be spiritually identical with Gandhi's concept of *satyagraha*, which means "truth power." Likewise, telling the truth is at the heart of *kapu aloha*.

You have also inspired and connected with indigenous people and their sympathizers around the world. As a student of hula, I could feel the joy in your tent when you chanted the *oli* and danced the *hula* in praise of the mountain, the waters, and the people who are defending their beliefs. When you came to my town of Santa Cruz, California, in November, you invited Valentin Lopez of the local Amah Mutsun tribe to speak, and he said, "We [indigenous people] are the only people with the moral authority to speak for this land." These kinds of conflicts have arisen before. The Tohono O'odham Nation protested the VERITAS gamma ray detector on Kitt Peak in Arizona, and the San Carlos Apache opposed several telescopes on Mt. Graham, also in Arizona. Both tribes succeeded at delaying, preventing, or relocating these telescopes. Of course, the use of sacred lands is only one of the many challenges facing indigenous peoples. But I believe that protests related to sacred lands have been especially effective, precisely because they force American society to confront and acknowledge your deepest values as a people.

That brings me to your third accomplishment: You are changing the culture of astronomy. It is no accident that we always want to put telescopes on mountaintops,

You are much more like the astronomers than you realize. Both of you, native Hawaiians and astronomers, learn by careful observation.

and these mountains are usually sacred to somebody. We are not *entitled* to build there. We need to ask permission, humbly. And asking permission means accepting that the answer might be "no." This is where the TMT board failed. They thought that once they held a hearing and received a permit, their job was done. We need to learn that *hearings* are not the same as *listening*, and a *permit* is not the same as *permission*.

I now come to the more difficult part of this letter, in which I tell you that the *kia'i*, too, have overlooked something. You are much more like the astronomers than you realize. Both of you, native Hawaiians and astronomers, learn by careful observation (*maka'ala*). You are *kia'i mauna*, watchers of the mountain. They are *kia'i o na hoku*, watchers of the stars. Each of you needs the other. Separately, you are out of balance. The *kia'i mauna* focus on their responsibility to their land and are blind (alas) to the epochal changes going on in our knowledge of the stars. The *kia'i o na hoku* focus on their quest to understand the skies, and forget sometimes their responsibility to the earth and its inhabitants. The two of you need each other and always will, and for that reason this drama cannot end with the victory of one side over the other. The only end is reconciliation, which can only come through dialogue conducted in the spirit of *aloha*.

EYE OF THE STORM The Thirty Meter Telescope, seen here in an artist rendering, would be the largest visible-light telescope in the world, allowing astronomers to explore exoplanets and the formation of stars and galaxies. Mauna Kea is an ideal site for capturing sharp images, scientists say, because Hawaii's atmosphere is calm, cool, and often free of clouds.



When you propose to shut down the Thirty Mile Telescope, you are proposing that we should shut our eyes to our own family.

I mentioned above the new things we are learning about the stars. Let me explain what I mean. Beginning in the mid-1990s, astronomers found ways to indirectly detect exoplanets, or planets orbiting other stars. We recognize them either through the wobble they create in their parent stars' orbits, or through the slight dimming of the star when the planet passes in front. We cannot yet see these exoplanets directly, because we do not have telescopes that are powerful enough. That is what the Thirty Meter Telescope is for. More than that, the TMT would give us the ability to probe those planets' atmospheres and look for oxygen. If we find that, it will be a sign to us: "Here is life."

According to Hawaiian legend, in the early days of creation, the gods spoke with man through the *kahunas*, and man spoke with the gods. The gods are still speaking to man, but in a different way than before. One thing we are learning from them is that our sky father, Wakea, was much busier than we thought. He created millions of other worlds. And on some of these planets, the most favored ones, he may have created other living beings.

We do not know what form they may have. They may be nothing more than one-celled organisms. We do not even have scientific proof that they exist, in part because we do not have the TMT yet. But I feel sure that there are some among you, dear *kia'i*, who know in your gut—in your *na'au*—that life does exist out there in the cosmos. If you know this, then you must know also that they are your family. They are your cousins just as surely as the taro plant, Wakea's firstborn child, is your brother.

When you propose to shut down the TMT, you are proposing that we should shut our eyes to our own family. *Your* own family. This has nothing to do with being for or against science. It is not *pono*. It violates what I have learned about Hawaiian culture, that *ohana* comes first.

As you know, the astronomers have a plan B, to build the telescope in the Canary Islands. Gordon Squires, vice president for external affairs of the TMT, tells me that the effect will be to make the science take twice as long, because there are about half as many nights with good seeing on the Canary Islands. Still, the universe can wait. The one-celled organisms will still be there even if we take twice as long to find them.

I'm not worried about that. I'm worried about you, native Hawaiians. What will be the effect on you when you abandon your *kuleana*, your responsibility to Wakea? He brought you to this island and made you stewards of this unique mountain, the mountain you named after him. Mauna Kea is the umbilical cord joining earth to the stars. It is a place that Wakea has designated for looking up as well as for looking down. He could not entrust this place to anyone else. He had to choose gatekeepers who could look in both directions: a caretaking people who valued their connection to the earth, and a voyaging people who valued their connection to the stars. He would not want you to succeed in only half of your mission.

Suppose that, by the power of *kapu aloha* and the grace of the gods, you agree that my words are true. What then would I ask you to do? I would ask for only one change at first, small but profound. Over and over, the *kia'i* have referred to the TMT as a "desecration" of the sacred mountain. It is not, and the word should not be uttered again. Instead I ask you to acknowledge that the observatory will *consecrate* a small part of the

mountain to a purpose intended by your own gods. Your mission is not to oppose this consecration, but to make sure that it is done right. Be *pono*, and make sure that the astronomers are *pono* too.

What do I mean by “doing it right”? A long list of things, some of which may not be easy. First, there should be native Hawaiian astronomers. Jessica Dempsey, deputy director of the East Asian Observatory, says that there are currently no native Hawaiian astronomers at any of the 13 telescopes on the mountain. This is a scandal. Though there are many native Hawaiian engineers doing outstanding work on the mountain, it is the astronomers who provide the vision, and they cannot fulfill their job without native Hawaiian eyes.

When I call for native Hawaiian astronomers, it is of course the responsibility of the astronomy community, but it is also your responsibility. Brialyn Onodera, a native Hawaiian engineer who works at one of the telescopes on Maui, wrote in the *Honolulu Civil Beat* that the protests have created a climate in which “telescope” has become a dirty word. (She is not the only one saying this; I have interviewed others.)

You, the *kia'i*, can reverse this message. You can teach native Hawaiian children that astronomy is a sacred responsibility (or *kuleana*) that has been given to your people. Teach your children that there are two types of astronomy, just as there are two types of hula. We have *kahiko*, done in the ancient style with no instruments except chanting and drums, and we have *'auana*, done in the modern style, with Western music and instruments. No one protests against *hula 'auana*, or calls it a desecration. We all recognize that it is another valid expression of what it means to be Hawaiian. Likewise, you can encourage some of your children to become *kahiko* astronomers, practicing the ancient methods of navigation, while others become *'auana* astronomers, fulfilling their *kuleana* with the best instruments that Western science can devise. Both of these missions should be treated with equal respect.

Should you reverse your opposition to the TMT, a cause that some of you have given 10 years of your life to? I leave this choice to your own conscience. In any case, there is other work to be done. The Master Lease awarding management of the Mauna Kea Science Reserve to the University of Hawaii will expire in

2033. It seems to me that any decision about individual facilities should wait until the issue of who will manage the mountain next is resolved. The *kia'i* deserve a place at the table, and I hope you will take it. You have earned the power to say no, but you have also earned something greater: the power to say yes.

This voyage of discovery, this quest to reunite the family of Wakea, will not be a short one. It will not end when TMT is built, or not built. It will not end when the Master Lease is renewed, or not renewed. The quest will last for centuries. All that we are asking, all that the gods are asking, and all that your children are asking, is for you to join us. At the helm, where you have always been.

In the spirit of *kapu aloha*,
—Dana Mackenzie

DANA MACKENZIE is a mathematician who went rogue and became a freelance writer. His first book, *The Big Splat*, was about the origin of the moon, and his most recent book, *The Book of Why* (co-written with Judea Pearl) explores the controversial subject of causation in science. He has also written for *The New York Times* about his experience as a male learning to dance hula.



The Man Who Saw the Pandemic Coming

Will the world now wake up to the global threat of zoonotic diseases?

BY KEVIN BERGER

PHOTO BY AP



DENNIS CARROLL DOESN'T MEAN to sound callous when he says the coronavirus outbreak was predictable. And he doesn't. He sounds sympathetic to people frightened by the outbreak. He has been an eyewitness to people around the world suffering from similar viruses. Most of all, Carroll sounds authoritative.

For decades, Carroll has been a leading voice about the threat of zoonotic spillover, the transmission of pathogens from nonhuman animals to us. Scientists are confident the current outbreak, which began in Wuhan, China, stemmed from a virus inherent in bats. In 2009, after years of studying infectious diseases at the Centers for Disease Control and Prevention, and the United States Agency for International Development (USAID), Carroll formed a USAID program called PREDICT, where he guided trailblazing research into viruses hiding, and waiting to emerge, in animals around the world.

"Dennis is a visionary," says Christine K. Johnson, an epidemiologist at the One Health Institute at the University of California, Davis, where she is a professor in the School of Veterinary Medicine. "He took the reactive approach to infectious diseases and turned it on its head. He said, 'We're going to work on a proactive approach to help countries prepare for the emergence of infectious diseases.'" Johnson, an investigator at PREDICT for 10 years, says Carroll was a pioneer in looking beyond livestock. "Dennis saw that emerging infectious diseases, far and wide, have mostly come from wildlife, and there needed to be investment in research in the wildlife sector." For a decade, PREDICT received annual federal funding of \$15 to \$20 million. In 2019, its funding wasn't renewed. Carroll left USAID and formed a new program, the Global Virome Project,

"to build on PREDICT's scientific insights and experience," he says.

In conversation, scientific insights, based on his experience, emerge from Carroll with a sting, whether he's talking about the biology of viruses or the stagnant response to the outbreak from the White House. I began by asking about the source of the outbreak.

How did the current coronavirus pass from a bat to humans?

We don't know specifically, but presumably the virus was being shed by the animal in the market, and humans were proximal. Or it could have been that people were directly handling the animal. There may have been a secondary source. In the 2002 SARS outbreak in China, we didn't see people's direct exposure to bats as the source of infection. There was a secondary source, a wildlife animal, the civet cat.

Could the transmission have resulted from people eating the wildlife?

Typically the preparation of the animal is where you have exposure. By the time it's cooked and prepared, the virus would have been dead. It's more common that transmission is through the animal shedding or people slaughtering the animal, when they're exposed to bodily fluids, blood, and secretions. With the avian influenza from poultry, a lot of the exposure and infections go

back to the preparation of chicken for cooking. In Egypt, for instance, when you look at who was infected, more common than not it was a woman, directly responsible for slaughtering and preparing the animal.

In 2018, you and colleagues wrote in *Science*, “Our ability to mitigate disease emergence is undermined by our poor understanding of the diversity and ecology of viral threats.” What do we need to understand about the diversity and ecology of viral threats?

The first thing to understand is that whatever future threats we’re going to face already exist; they are currently circulating in wildlife. Think of it as viral dark matter. A large pool of viruses are circulating and we don’t become familiar with them until we see a spillover event and people getting ill.

Do bats have a particularly high potential for spillover?

Certainly. We’ve been able to identify bats as reservoirs for coronaviruses and documented specific bat populations as reservoirs for Ebola virus. We want to understand how each of these bats operate within an ecosystem. Do they have certain behaviors and practices that either keep them remote from or proximal to human populations? The bat population in which we isolated the Ebola virus in West Africa was a species of bat that also tends to co-roost within human housing, so it elevates the opportunity for spillover.

Have there been disturbances in their environments that have brought bats closer to us?

The disturbances in their environments are us. We’ve penetrated deeper into ecozones we’ve not occupied before.

What’s a telling example of our incursion?

In Africa, we see a lot of incursion driven by oil or mineral extraction in areas that typically had few human populations. The problem is not only moving workers and establishing camps in these domains, but building roads that allow for even more movement of populations. Roads also allow for the movement of wildlife animals, which may be part of a food trade, to make their way into urban settlements. All these dramatic changes increase the potential spread of infection.



ON SITE While in Vietnam being filmed for the recent Netflix documentary series, *Pandemic*, Dennis Carroll took a moment to pose with two members of the Vietnamese crew.

This is a global event. It is going to hit every community everywhere in the world.

Are spillover events more common now than 50 years ago?

Yes. EcoHealth Alliance, an NGO, and others, looked at all reported outbreaks since 1940. They came to a fairly solid conclusion that we're looking at an elevation of spillover events two to three times more than what we saw 40 years earlier. That continues to increase, driven by the huge increase in the human population and our expansion into wildlife areas. The single biggest predictor of spillover events is land-use change—more land going to agriculture and more specifically to livestock production.

Is there something specific about a virus that makes it zoonotic?

You can argue viruses aren't living organisms. They're sheets of proteins encapsulating some DNA or RNA. Beyond that, they have no machinery to be able to live on their own. They're looking for an ecosystem that has all of the other cellular machinery essential for replication. They can't live outside another animal population.

They need that animal to replicate. And we're just one more animal. We think of ourselves as something special. But viruses are infecting us with exactly the same purpose they infect a bat or a civet cat.

Viruses live on a delicate balance, don't they? They have to be able to thrive without killing their host.

Right. The ones that kill off their host quickly will disappear. With the SARS virus, it's no surprise that killing 10 percent of its host, it wasn't able to establish itself as a pandemic virus on this planet.

Are there any signs that this coronavirus will kill itself?

This one has a lower pathogenicity. The lower its virulence, the more likely it'll become part of an endemic, part of a seasonal event. That's one of the big things that's going to be a worry. If it does go quiet over the summer months, then the question's going to be, "Is it still infecting people?" We could be walking around in the middle of summer with influenza viruses, but they're not active. They've just gone quiet. When the

right ecology comes into play, it starts getting cold, and damp, then it starts replicating like crazy. If it's able to park itself, and not kill its host over the summer months, then we've got a virus that has all the telltale signatures of establishing itself as part of our normative landscape, much to our detriment.

Do you think the current outbreak was inevitable?

Oh, sure. It was predictable. It's like if you had no traffic laws and were constantly finding pedestrians getting whacked by cars as they crossed the street. Is that surprising? No. All you need to do is to better manage how we set up crosswalks, how we establish traffic rules and regulations. We're not doing that. We're not establishing the kind of safe practices that will minimize the opportunity for spillover. If we better understood where these viruses are circulating and understood that ecology, we would have the potential to disrupt and minimize the risk of spillover.

Why aren't we—governments and policymakers—doing that?

First, this is an expanding problem driven by unprecedented population change. It's only in the last 100 years that we've begun adding people at a rate that's causing this incredible disruption of the larger ecosystem. If you and I were having this discussion 100 years ago, there were 6 billion fewer people on this planet. It took us the better part of our total existence of the species, 300,000 years, before we hit the 1 billion mark. But in 100 years we've added 6 billion people and we'll add another 4 to 5 billion before the end of this century.

Second, governments and society by and large are governed by inertia. We don't change and adapt and evolve very quickly. And we're barely cognizant as a global society that the world we're living in today is fundamentally different than the world our species has ever lived in. You know that old saw that if you drop a frog in a pot of boiling water, it will leap out. But if you take that same frog and put it in a pot of ambient water and slowly crank up the temperature, it will stay in that water and boil to death. It loses perspective on the changing environment around it. We're that frog in the ambient water. We're oblivious to the conditions that have enabled zoonotic viruses to become integrated into us.

We think of ourselves as special. But viruses are infecting us with the same purpose they infect a bat.

What first really opened your eyes to the scale of the spillover problem?

You mean my Saul on the road to Damascus moment?

Exactly.

It was avian influenza in the 2000s. What you saw with avian influenza was a direct consequence of how much poultry was being produced to feed people. If you look at China today, it produces something on the order of 15 to 20 billion poultry per year. But if you went back and you looked at the data from the 1960s, you see that, at best, only a few hundred million poultry were under production. When you look in Bangladesh, Vietnam, and elsewhere in Asia and Indonesia, you see that the amount of poultry that was being produced 50 years ago was orders of magnitude less than poultry being produced today. That's a consequence of more people and more purchasing power. One of the things we know about household purchasing power is that when you have disposable income in your hands, you're going to move from a root- or grain-based diet and try to get animal protein. And that's what happened.

One statistic that jumps out of what you wrote in *Science* is there are 1.67 million viruses on Earth and an estimated 631,000 to 827,000 have the capacity to infect people. That's pretty frightening, no?

On one level it is pretty frightening. But on another level the potential to infect doesn't necessarily correlate with illness and death. Some viruses may not have any consequence at all. And some may be involved in enhancing our own biology. They could become part

of our microbiome. It's nothing new in the course of evolution. We have to be open to the idea that viruses aren't simply our enemies, that they may have an important and positive role to play for us. We found that out about bacteria. At the same time, we have to keep our eyes open and be cautious about the pharmaceuticals we take. If we're taking broad-spectrum antivirals, they could be opening up other complications.

How would you describe the general attitude of the United States government toward the threat of zoonotic diseases?

It's not just the U.S. government but governments at large and the private sector—we don't invest in risk. Talking about zoonotic diseases is different than talking about tuberculosis or malaria. Those are tangible. They are clear and present problems. Zoonotic diseases are an emerging problem. But we as a society don't invest in things that are not kicking our door down.

The coronavirus is kicking our door down now, don't you think?

Yes, it's got everyone's attention. But this coronavirus will fall off the headlines and when it does, you will see a contraction in the kind of investments that are made in it. We have war budgets and then no monies during peacetime. So part of the challenge—it's a social engineering exercise—is getting lawmakers and investors to invest in risk. That's really difficult.

The fact that your PREDICT program was not refunded has become a political rallying point against President Trump, who has shown an ignorance of science. Do you think there's a connection between the end of PREDICT and what has happened with the coronavirus?

No, I don't think so. PREDICT was a beautiful project. It was scientifically well executed. It was forward-leaning. But its scale was small. It discovered slightly more than 2,000 viruses. If you're going to have a public health impact, finding 2,000 viruses out of a pool of 600,000, over 10 years, isn't going to transform your ability to minimize public health risk. And PREDICT didn't really navigate the second step in a critical equation—turning science into policy. We didn't design it for that purpose. Also, even an annual budget of \$20 million is not sufficient. You'd need about \$100

I'm stunned by the absolute absence of global dialogue for what is a global event.

million a year to carry out the kind of global program that would give us evidence to transform how we think about viral risk and how we should prepare for it. That's what my new Global Virome Project aims to do.

What worries you about this coronavirus?

There's the obvious stuff that's worrying everyone. But there are things not being talked about. Those are the things that worry me the most. This is a global event. It is going to hit every community everywhere in the world. And the impact will not be equally distributed because there are parts of the world that have health care systems that are far more fragile than ours or China's or Europe's. We know that when fragile healthcare systems have extraordinary new demands put on them, there's an enormous risk those health systems will collapse. Specifically in the Africa region and regions where there's civil disorder or war.

In 2014, when the Ebola virus swept across the three countries of West Africa, we saw that one of the immediate consequences of the virus was to essentially shut down health-service delivery. Health workers became exposed, sickened, and fearful. For five months, you did not have health services that were tending to people's normative healthcare. Pregnant women didn't have access to trained birth attendants. Kids didn't have access to anti-malarials. Immunizations didn't go on. You had an undocumented population of people whose lives were compromised because they couldn't get routine health services. My fear is this will likely play itself out again. If the coronavirus continues to be as significant as it appears to be, we're going to see health systems get overloaded and not be capable of responding to both the virus and normative health issues. No one in government seems to be talking about this.

In 2005, during the avian influenza, George W. Bush was on the phone routinely with leaders around

There are things about this outbreak that are not being talked about. Those are the things that worry me the most.

the world about how to coordinate a global response. Barack Obama did the same in 2009 for the second H1N1 pandemic and in 2014 for the Ebola epidemic. You saw presidential leadership step up and act as a catalyst for forging a global way forward for a global problem. It has been absolute silence in this White House. I think the only reason the White House is even paying any lip service to this is because the stock market has gone into a free fall. So they're trying to figure out what are the words they need to say to placate the stock market.

Why do you think there's been silence in this White House?

Because the Trump administration is only interested in America first. Populism here and across Europe and elsewhere has fragmented the global networks, which had been so instrumental in being able to bring together a global approach to problems like this. I've not seen any reports coming out of the White House that showed that as China was struggling to bring the virus under control, our president reached out to President Xi to talk about how to coordinate action. I'm stunned by the absolute absence of global dialogue for what is a global event. In Europe right now, you would never believe that there was a European Union. From where I sit, it looks like every country is making this up as they go along. Italy isn't coordinating with Brussels. Brussels isn't coordinating with Germany. There's no coherent regional approach to this problem in Europe, even though they have a platform for doing it.

So what will it take to make people aware of the global threat of zoonotic diseases?

There's nothing like a serial assault to heighten your awareness, and that's what we're looking at. We're on a cycle of about every three years of getting something like this. And each time that happens, there's more awareness that these investments need to be made and sustained. The problem is getting these monies as part of the annual regular non-emergency funding.

There's been exemplary sharing of data among scientists and geneticists, don't you think?

Yes. But think of the syllogism from Socrates: right thinking leads to right action. We know that's not the case. Your thoughts can be absolutely right on, but your practices can be completely divergent. What science allows us to do is understand, with greater granularity, what's at risk. Science will give us insight. But we have to translate that insight into a sustained valuation of risk and move that forward.

How, ideally, should we move forward?

These viruses inherently have the ability to mutate. What we're looking at today isn't necessarily what we'll be looking at in a few months. It could become more deadly or it could attenuate and disappear, like the common cold. The big issue is: Are we tracking that? Do we have enough data and transparency and the availability of samples? What's showing up in Iran? What's showing up in Israel? What's showing up in Italy? What's showing up in the United States? Is there enough open transparency in real time that allows us to keep our finger on the pulse? I'm an internationalist. Figure out how to care for our people. Pay attention to communities around the world that need assistance. We're all part of the same ecosystem. This is a global issue. We either prepare for it and respond to it in the context of a global lens, or we don't. If our preparations and responses are country-centric, we're in for some serious trouble. ☹️

KEVIN BERGER is the editor of *Nautilus*.

Gaia Will Soon Belong to the Cyborgs

The father of the Gaia principle on the coming age of hyperintelligence

BY JAMES LOVELOCK





OUR REIGN AS SOLE UNDERSTANDERS of the cosmos is rapidly coming to an end. We should not be afraid of this. The revolution that has just begun may be understood as a continuation of the process whereby the Earth nurtures the understanders, the beings that will lead the cosmos to self-knowledge. What is revolutionary about this moment is that the understanders of the future will not be humans but cyborgs that will have designed and built themselves from the artificial intelligence systems we have already constructed. These will soon become thousands then millions of times more intelligent than us.

The term cyborg was coined by Manfred Clynes and Nathan Kline in 1960. It refers to a cybernetic organism: an organism as self-sufficient as one of us but made of engineered materials. I like this word and definition because it could apply to anything ranging in size from a microorganism to a pachyderm, from a microchip to an omnibus. It is now commonly taken to mean an entity that is part flesh, part machine. I use it here to emphasize that the new intelligent beings will have arisen, like us, from Darwinian evolution. They will not, at first, be separate from us; indeed, they will be our offspring because the systems we made turned out to be their precursors.

We need not be afraid because, initially at least, these inorganic beings will need us and the whole organic world to continue to regulate the climate, keeping Earth cool to fend off the heat of the sun and safeguard us from the worst effects of future catastrophes. We shall not descend into the kind of war between humans and machines that is so often described in science fiction because we need each other. Gaia will keep the peace.

This is the age I call the “Novacene.” I’m sure that one day a more appropriate name will be chosen, something more imaginative, but for now I’m using Novacene to describe what could be one of the most crucial periods in the history of our planet and perhaps even of the cosmos.

Cyborgs may be the start of a process that leads toward an intelligent universe.

WE SHALL BE PARENTS of the cyborgs and we are already in the process of giving birth. It is important we keep this in mind. Cyborgs are a product of the same evolutionary processes that created us.

Electronic life depends on its organic ancestry. I can see no way for non-organic life forms to evolve, *de novo*, on another Earth or any other planet from the mix of chemicals and in the physical conditions common in the universe. For cyborg life to emerge requires the services of a midwife. And Gaia fits the role.

It seems probable that organic life must always precede electronic life. Indeed, had it been easy for the components of electronic life to assemble on a planet, the rate at which such a life form evolves would by now have filled the universe with life. The fact that the observable universe so far appears barren strongly suggests that electronic life cannot form automatically from solar debris.

Parents we may be, but equals we cannot be. This raises a huge problem that cannot be solved by technical or scientific expertise. How do we plan our diplomacy in the last years of the Anthropocene, so that flesh-and-blood humans, together with the wet chemical life of Gaia, can enjoy a peaceful retirement during the first stage of the transition from organic to inorganic life?

Negotiations between the two species are almost impossible to imagine. They would be likely to see us as we see plants—as beings locked in an extraordinarily slow process of perception and action. Indeed, when the Novacene is established, cyborg scientists may well exhibit collections of live humans. After all, people who live near London go to Kew Gardens to watch the plants.

I sense that the cyborg world is as difficult for one of us to comprehend as the complexities of our world are to a dog. Once the cyborgs have become established, we will no more be the masters of our creations than our much-loved pet is in charge of us. Perhaps our best option is to think this way, if we want to persist in a newly formed cyber world.

A child is not born with an immediate ability to understand its environment. It takes many months before it senses the world and years before it can change it. It may be a false memory, but I recall vividly a dream of lying in the sunshine in the garden and

experiencing a sense of great comfort and somehow recognizing that this was life. If it was an authentic experience it must have taken place in my second year of life. For a new-built cyborg, this coming alive would take about an hour.

Such acceleration also applies to speed of response. Early organic life that existed as separate individual cells could respond to an environmental change, such as light intensity, acidity, the presence of food, in about one second. By contrast, cyborgs could probably detect a change in light level occurring in a femtosecond (one quadrillionth of a second), a million million times faster than organic life.

Yet, in spite of the limitations of its chemical and physical nature, organic life achieves sensitivities to change near the very limits of possibility. At its best, human hearing can detect a sound with an amplitude equal to a tenth of the diameter of a proton. Human sight is so sensitive that if it were only slightly more sensitive we would see a set of flashes in the night sky as individual quanta of light illuminating our retinas. Impressive though these adaptations are, organic life will never be able to match the speed and sensitivity of cyborgs.

Memory is another matter. Both organic and electronic memories are impressively great and here the race is still on, as it is with longevity. After nearly 100 years of life I can still remember the details of my grandmother's garden and even persuade myself to imagine that the detail is photographic. Now imagine the response of a young cyborg to the human shout of victory at a sports event. Does it react emotionally, just as humans do? I wonder if it will be for them as it is with us—so that the sense of time varies with the occasion.

THE ARRIVAL OF THE CYBORGS and the Novacene will be further evidence of the two great issues—are we alone in the cosmos and is the entire cosmos destined to attain consciousness? On the subject of aliens, I think the Novacene will add weight to my conviction that they don't exist.

In 1950 at the Los Alamos National Laboratory, the physicist Enrico Fermi was on his way to lunch with three colleagues. They were discussing the epidemic of UFO sightings that had afflicted the United States—the

Cyborgs will soon become thousands of times more intelligent than us.

Cyborgs are a product of the same evolutionary processes that created us.

famous Roswell incident involving a UFO crash had happened three years before, and by 1950 aliens seemed to be everywhere. None of these reports was remotely convincing to Fermi and during lunch he suddenly blurted out, “Where are they?”

This chance remark has undermined alien spotters ever since. Fermi’s point was that, if we are here, they should also be here, but they aren’t. There are billions of stars in our galaxy and sextillions in the observable cosmos. We now know there are also many planets which could be inhabited by aliens with much higher technological capabilities than humans. If they, like us, pursued space flight, then the immense age of the cosmos would mean they could have at least traversed our galaxy. In short, aliens should be swarming about the place—but they aren’t.

As with interstellar travel, so with hyperintelligence. If we do give birth to the cyborgs, does it not imply that we really are the first and only intelligence in the universe? Had there been a predecessor like us, the artificial intelligence they created would long ago have answered Fermi’s paradox. If someone like us had appeared before and then proceeded to artificial intelligence, this new physical intelligence might now dominate the universe. Surely it would be easy for astronomers to detect its presence. It would be everywhere.

Once again we must remember the time involved in producing understanding creatures. When thinking of the evolution of intelligence it is important to keep in mind how slow a process it is. The cosmos itself is 13.8 billion years old. After it started, a few billion years must have been spent on cosmic evolution. How long did the period of monstrously large hydrogen-only stars last? A star 1,000 times more massive than our sun has a lifetime of about 1 million years. These would be too big and too short-lived to allow life to emerge in their vicinity. Then eventually, somehow, our sun appeared, probably in a globular cluster. It must have lived close to violent neighbors which exploded as supernovae that littered the cluster with the elements of life. Then, after all this, there still remained 4 billion years until we emerged.

So not only are we alone in the universe, our cyborg successors will also be alone. They, too, will find themselves the sole understanders in an otherwise lifeless cosmos. They will, of course, be far better equipped

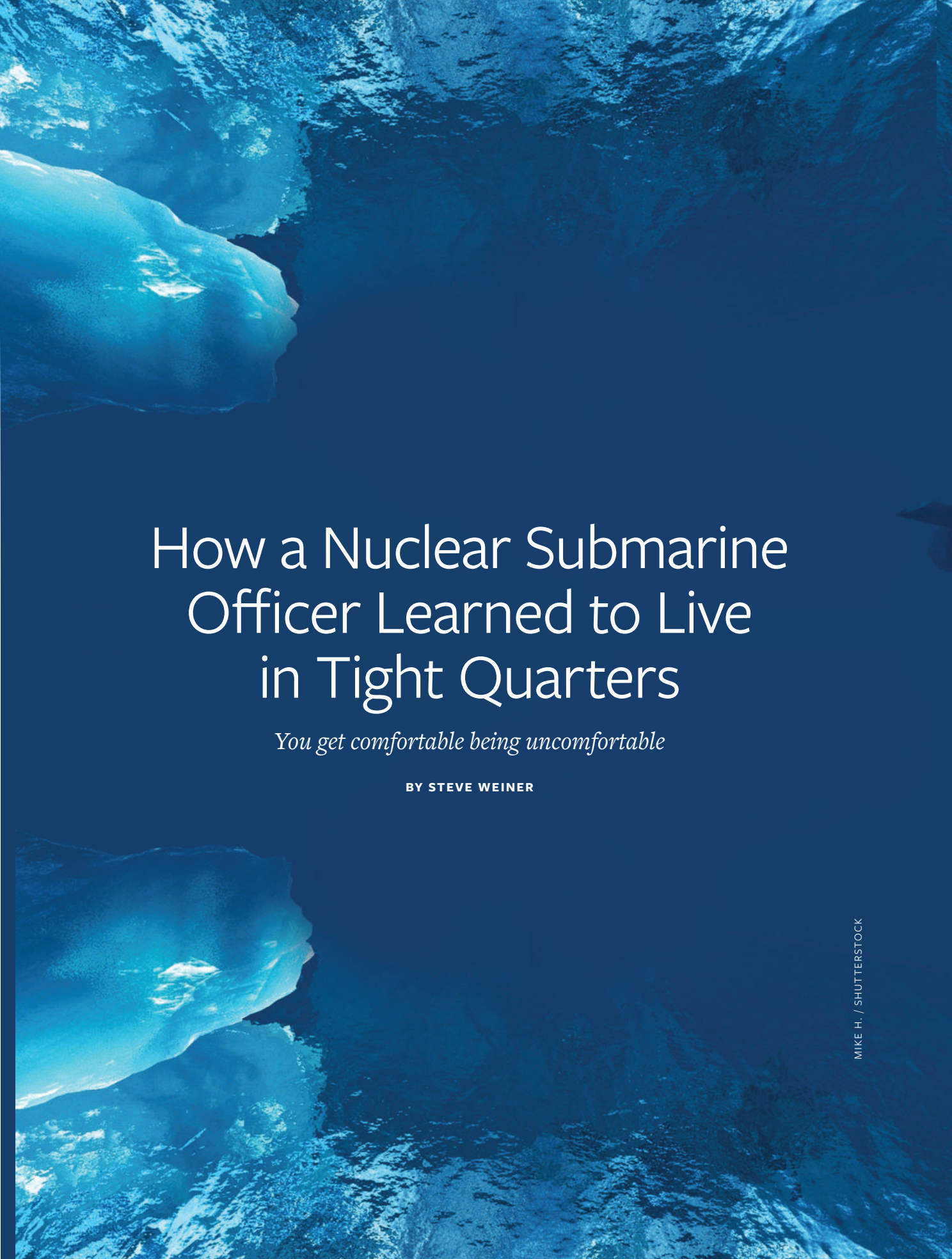
for the task of understanding. Perhaps, if the cosmic anthropological principle is correct, they will be the start of a process that leads toward an intelligent universe. By setting free the cyborgs, there may be a small chance that they will evolve able to complete the purpose of the universe, whatever that may be. Perhaps the final objective of intelligent life is the transformation of the cosmos into information.

Must we fear the future and the surprises the Novacene might bring? I do not think so. This epoch will mark the end of what is to us nearly 4 billion years of biological life on this planet. As humans with emotions, surely it is something of which we should be proud as well as sad. If John Barrow and Frank Tipler (*The Anthropic Cosmological Principle*) are right and the universe exists to produce and sustain intelligent life, then we are playing a part like that of the photosynthesizers, organisms that set the scene for the next stage of evolution.

The future is, for us, unknowable, as it always has been, even in an organic world. Cyborgs will conceive cyborgs. Far from continuing as low-life which is there for our convenience, they will evolve and could be the advanced evolutionary products of a new and powerful species. But for the dominating and overwhelming presence of Gaia, they would in no time be our masters. ☺

JAMES LOVELOCK is the originator of the Gaia hypothesis (now Gaia theory). His many books on the subject include *Gaia: A New Look at Life on Earth*, *The Revenge of Gaia*, *The Vanishing Face of Gaia*, and *A Rough Ride to the Future*. The author of more than 200 scientific papers, he was elected a Fellow of the Royal Society in 1974.

This article was adapted from *Novacene: The Coming Age of HyperIntelligence*, by James Lovelock, with Bryan Appleyard, published in 2019 by MIT Press.

An underwater photograph showing a large, translucent blue ice formation on the left side, with sunlight filtering through the water, creating a deep blue background.

How a Nuclear Submarine Officer Learned to Live in Tight Quarters

You get comfortable being uncomfortable

BY STEVE WEINER



I'M NO STRANGER to forced isolation. For the better part of my 20s, I served as a nuclear submarine officer running secret missions for the United States Navy. I deployed across the vast Pacific Ocean with a hundred other sailors on the USS Connecticut, a Seawolf-class ship engineered in the bygone Cold War era to be one of the fastest, quietest, and deepest-diving submersibles ever constructed. The advanced reactor was loaded with decades of enriched uranium fuel that made steam for propulsion and electrical power so we could disappear under the waves indefinitely without returning to port. My longest stint was for two months, when I traveled under the polar ice cap to the North Pole with a team of scientists studying the Arctic environment and testing high frequency sonar and acoustic communications for under-ice operations. During deployments, critical-life events occur without you: holidays with loved ones, the birth of a child, or in my case, the New York Giants 2011-2012 playoff run to beat Tom Brady's Patriots in the Super Bowl for the second time. On the bright side, being cut off from the outside world was a great first job for an introvert.



OFFICER OF THE DECK Author Steve Weiner in 2011, on the USS Connecticut, a nuclear submarine. Weiner was the ship's navigator. Submarine and crew, with a team of scientists, were deployed in the Arctic Ocean, studying the Arctic environment and testing high frequency sonar and acoustic communications for under-ice operations.

It's been a month since COVID-19 involuntarily drafted me into another period of isolation far away from home. I'm in Turkey, where a two-week trip with my partner to meet her family has been extended indefinitely. There were no reported cases here and only a few in California in early March when we left San Francisco, where I run a business design studio. I had a lot of anticipation about Turkey because I'd never been here. Now I'm sheltering in a coastal town outside of Izmir with my partner, her parents, their seven cats, and a new puppy.

Shuttered in a house on foreign soil where I don't speak the language, I have found myself snapping back into submarine deployment mode. Each day I dutifully monitor online dashboards of data and report the status of the spread at the breakfast table to no one in particular. I stay in touch with friends and family all over the world who tell me they're going stir crazy and their homes are getting claustrophobic. But if there is one thing my experience as a submarine officer taught me, it's that you get comfortable being uncomfortable.

COURTESY OF STEVE WEINER

My training began with psychological testing, although it may not be what you think. Evaluating mental readiness for underwater isolation isn't conducted in a laboratory by clipboard-toting, spectacled scientists. The process to select officers was created by Admiral Hyman Rickover—the engineering visionary and noted madman who put the first nuclear reactor in a submarine—to assess both technical acumen and composure under stress. For three decades as the director of the Navy's nuclear propulsion program, Rickover tediously interviewed every officer, and the recruiting folklore is a true HR nightmare: locking candidates in closets for hours, asking obtuse questions such as “Do something to make me mad,” and sawing down chair legs to literally keep one off balance.

Rickover retired from the Navy as its longest-serving officer and his successors carried on the tradition of screening each officer candidate, but with a slightly more dignified approach. Rickover's ghost, though, seemed to preside over my interview process when I applied to be a submariner as a junior at the U.S. Naval Academy in Annapolis, Maryland. I was warned by other midshipmen that I would fail on the spot if I initiated a handshake. So, dressed in my formal navy blue uniform and doing my best to avoid tripping into accidental human contact, I rigidly marched into the Admiral's office, staring straight ahead while barking my resume. When I took a seat on the unaltered and perfectly level chair in front of his desk, the Admiral asked me bluntly why I took so many philosophy classes and if I thought I could handle the technical rigors of nuclear power school. My response was a rote quip from John Paul Jones' “Qualifications of a Naval Officer.” “Admiral, an officer should be a gentleman of liberal education, refined manners, punctilious courtesy, and the nicest sense of personal honor.” My future boss looked at me, shook his head like he thought I'd be a handful, and told me I got the job.

Nuclear power training is an academic kick in the face every day for over a year. The curriculum is highly technical and the pedagogy resembles a cyborg assembly-line without even a hint of the Socratic method. Our grades were conspicuously posted on the classroom wall and a line was drawn between those who passed and those who failed. I was below the line enough to earn the distinguished dishonor of 25

Confinement opened something up in my psyche and I gave myself permission to let go of my anxieties.

additional study hours each week, which meant I was at school at 5 a.m. and every weekend. This is how the Nuclear Navy builds the appropriate level of knowledge and right temperament to deal with shipboard reactor operations.

I finally sat down for a formal psychological evaluation a few months before my first deployment. I was ushered into a room no bigger than a broom closet and instructed to click through a computer-based questionnaire with multiple-choice questions about my emotions. I never did learn the results, so I assume my responses didn't raise too many red flags.

During my first year onboard, I spent all my waking hours either supervising reactor operations or learning the intricacies of every inch of the 350-foot tube and the science behind how it all worked. The electrolysis machine that split water molecules to generate oxygen was almost always out of commission, so instead we burned chlorate candles that produced breathable air. Seawater was distilled each day for drinking and shower water. Our satellite communications link had less bandwidth than my dial-up modem in the 1990s and we were permitted to send text-only emails to friends and family at certain times and in certain locations so as not to risk being detected. I took tests every month to demonstrate proficiency in nuclear engineering, navigation, and the battle capabilities of the ship. When I earned my submarine warfare qualification, the Captain pinned the gold dolphins insignia on my uniform and gave me the proverbial keys to the \$4 billion warship. At that point, I was responsible for coordinating missions and navigating the ship as the Officer of the Deck.

The electrolysis machine was out of commission, so we burned chlorate candles that produced breathable air.

Modern submarines are hydrodynamically shaped to have the most efficient laminar flow underwater, so that's where we operated 99 percent of the time. The rare exception to being submerged is when we'd go in and out of port. The most unfortunate times were long transits tossing about in heavy swells, which made for a particularly nauseated cruise. To this day, conjuring the memory of some such sails causes a reflux flashback. A submariner's true comfort zone is beneath the waves so as soon as we broke ties with the pier we navigated toward water that was deep enough for us to dive.

It's unnatural to stuff humans, torpedoes, and a nuclear reactor into a steel boat that's intentionally meant to sink. This engineering marvel ranks among the most complex, and before we'd proceed below and subject the ship and its inhabitants to extreme sea pressures, the officers would visually inspect thousands of valves to verify the proper lineup of systems that would propel us to the surface if we started flooding uncontrollably and sinking—a no-mistakes procedure called *rigging for dive*. Once we'd slip beneath the waves, the entire crew would walk around to check for leaks before we'd settle into a rotation of standing watch, practicing our casualty drills, engineering training, eating, showering (sometimes), and sleeping (rarely). The full cycle was 18 hours, which meant the timing of our circadian cycles were constantly changing. Regardless of the amount of government-issued Folger's coffee I'd pour down my throat, I'd pass out upon immediate contact with my rack (the colloquialism for a submarine bunk in which your modicum of privacy was symbolized by a cloth curtain).

As an officer, I lived luxuriously with only two other grown men in a stateroom no bigger than a walk-in closet. Most of the crew slept stacked like lumber in an 18-person bunk room and they all took turns in the rack. This alternative lifestyle is known as hot-racking, because of the sensation you get when you crawl into bedding that's been recently occupied. The bunk rooms are sanctuaries where silence is observed with monastic intensity. Slamming the door or setting an alarm clock was a cardinal sin so wakeups were conducted by a junior sailor who gently coaxed you awake when it was time to stand watch. *Lieutenant Weiner, it's time to wake up. You've got the midnight watch, sir.* Words that haunt my dreams.

I maintained some semblance of sanity and physical fitness by sneaking a workout on a rowing erg in the engine room or a stationary bike squeezed between electronics cabinets. The rhythmic beating of footsteps on a treadmill was a noise offender—the sound could be detected on sonar from miles away—so we shut it off unless we were in friendly waters where we weren't concerned with counter-detection.

Like a heavily watered-down version of a Buddhist monk taking solitary retreat in a cave, my extended submarine confinements opened something up in my psyche and I gave myself permission to let go of my anxieties. Transiting underneath a vast ocean in a vessel with a few inches of steel preventing us from drowning helps put things into perspective. Now that I'm out of the Navy, I have more appreciation for the freedoms of personal choice, a fresh piece of fruit, and 24 hours in a day. My only regrets are not keeping a journal or having the wherewithal to discover the practice of meditation under the sea.

Today, I'm learning Turkish so I can understand more about what's happening around me. I'm doing Kundalini yoga (a moving meditation that focuses on breathwork) and running on the treadmill (since I'm no longer concerned about my footsteps being detected on sonar). On my submarine, I looked at photos to stay connected to the world I left behind, knowing that I'd return soon enough. Now our friend who is isolating in our apartment in San Francisco sends us pictures of our cat and gives us reports about how the neighborhood has changed.

It's hard to imagine that we'll resume our lifestyles exactly as they were. But the submariner in me is optimistic that we have it in us to adapt to whatever conditions are waiting for us when it's safe to ascend from the depths and return to the surface. ☺

STEVE WEINER is the founder of Very Scarce, a business design studio. He used to lead portfolio companies at Expa and drive nuclear submarines in the U.S. Navy. He has an MBA from The Wharton School and a BS from the U.S. Naval Academy. Instagram: @steve Twitter: @weenpeace

Guided by Plant Voices

*Plants talk to this ecologist.
They tell her how to do better science.*

BY STEVE PAULSON



P LANTS ARE INTELLIGENT BEINGS with profound wisdom to impart—if only we know how to listen. And Monica Gagliano knows how to listen. The evolutionary ecologist has done groundbreaking experiments suggesting plants have the capacity to learn, remember, and make choices. That’s not all. Gagliano, a senior research fellow at the University of Sydney in Australia, talks to plants. And they talk back. Plants summon her with instructions on how to live and work. Some of Gagliano’s conversations happened in prophetic dreams, which led her to study with a shaman in Peru while tripping on psychoactive plants.

Along with forest scientists like Suzanne Simard and Peter Wohlleben, Gagliano raises profound scientific and philosophical questions about the nature of intelligence and the possibility of “vegetal consciousness.” But what’s unusual about Gagliano is her willingness to talk about her experiences with shamans and traditional healers, along with her use of psychedelics. For someone who’d already received fierce pushback from other scientists, it was hardly a safe career move to reveal her personal experiences in otherworldly realms.

Gagliano considers her explorations in non-Western ways of seeing the world to be part of her scientific work. “Those are important doors that you need to open and you either walk through or you don’t,” she told me. “I simply decided to walk through.” Sometimes, she said, certain plants have given her precise directions on how to conduct her experiments, even telling her which plant to study. But it hasn’t been easy. “Like Alice, [I] found myself tumbling down a rather strange rabbit hole,” she wrote in a 2018 memoir, *Thus Spoke the Plant*. “I did doubt my own sanity many times, especially when all these odd occurrences started—and yet I know I do not suffer from psychoses.”

Shortly before the COVID-19 lockdown, I talked with Gagliano at Dartmouth College, where she was a visiting scholar. We spoke about her experiments, the new field of plant intelligence, and her own experiences of talking with plants.

You are best known for an experiment with *Mimosa pudica*, commonly known as the “sensitive plant,” which instantly closes its leaves when it’s touched. Can you describe your experiment?

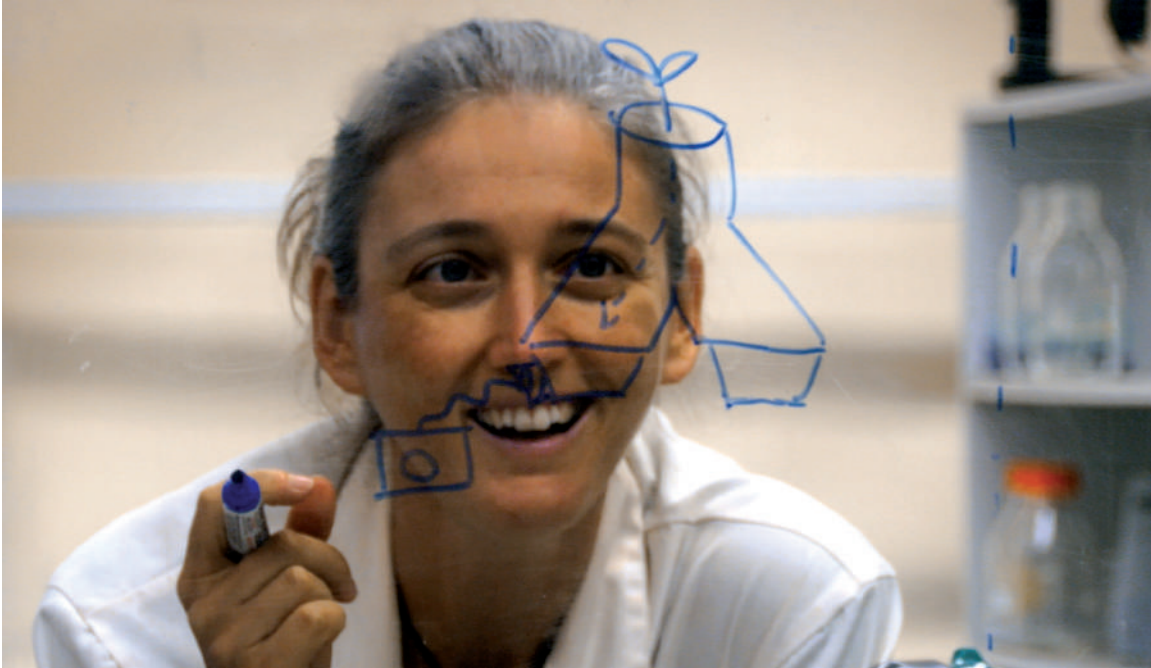
I built a little contraption that allowed me to drop the plants from a height of maybe 15 centimeters. So it’s not too high. When they fall, they land in a softly padded base. This plant closes its leaves when disturbed, especially if the disturbance is a potential predator. When the leaves are closed, big, spiny, pointy things stick out, so they might deter a predator. In fact, they not only close the leaf, but literally droop, like, “Look, I’m dead. No juice for you here.”

You did this over and over, dropping the plants repeatedly.

Exactly. It makes no sense for a plant or animal to repeat a behavior that is actually useless, so we learn pretty quick that whatever is useless, you don’t do anymore. You’re wasting a lot of energy trying to do something that doesn’t actually help. So, can the plant—in this case, *Mimosa*—learn not to close the leaves when the potential predator is not real and there are no bad consequences afterward?

After how many drops did they stop closing their leaves?

The test is for a specific type of learning that is called habituation. I decided they would be dropped continuously for 60 times. Then there was a big pause to let



PAVLOV'S PEAS Monica Gagliano sketches a pea plant in her lab at the University of Sydney (above). She conducted experiments with pea plants to determine if, like Pavlov's famous dogs, the plants learned to anticipate food. They did. "Although they do not salivate," Gagliano says.

them rest and I did it again. But the plants were already re-opening their leaves after the first three to six drops. So within a few minutes, they knew exactly what was going on—like, "Oh my god, this is really annoying but it doesn't mean anything, so I'm just not going to bother closing. Because when my leaves are open, I can eat light." So there is a tradeoff between protecting yourself when the threat is real and continuing to feed and grow. I left the plants undisturbed for a month and then came back and repeated the same experiment on those individuals. And they showed they knew exactly what was going on. They were trained.

You say these plants "understand" and "learn" that there's no longer a threat. And you're suggesting they "remember." You're not using these words metaphorically. You mean this literally

Yes, that's what they're doing. This is definitely memory. It's the same kind of experiment we do

with a bee or a mouse. So using the words "memory" and "learning" feels totally appropriate. I know that some of my colleagues accuse me of anthropomorphizing, but there is nothing anthropomorphic about this. These are terms that refer to certain processes. Memory and learning are not two separate processes. You can't learn unless you remember. So if a plant is ticking all the boxes and doing what you would expect a rat or a mouse or a bee to do, then the test is being passed.

Do you think these plants are actually making decisions about whether or not to close their leaves?

This experiment with *Mimosa* wasn't designed to test that specific question. But later, I did experiments with other plants, with peas in particular, and yes, there is no doubt the plants make choices in real decision-making. This was tested in the context of a maze, where the test is actually to make a choice between left and right. The

This is who I am. And nobody has the right to tell me that it's not real.

choice is based on what you might gain if you choose one side or the other. I did one study with peas that showed the plants can choose the right arm in a maze based on where the sound of water is coming from. Of course, they want water. So they will use the signal to follow that arm of the maze as they try to find the source of water.

So plants can hear water?

Oh, yeah, of course. And I'm not talking about electrical signals. We have also discovered that plants emit their own sounds. The acoustic signal comes out of the plant.

What kind of sounds do they make?

We call them clicks, but this is where language might fail because we are trying to describe something we're not familiar enough with to create the language that really describes the picture. We worked out that, yes, plants not only produce their own sound, which is amazing, but they are listening to sounds. We are surrounded by sound, so there are studies, like my own study, of plants moving toward certain frequencies and then responding to sounds of potential predators chewing on leaves, which other plants that are not yet threatened can hear. "Oh, that's a predator chewing on my neighbor's leaves. I better put my defenses up." And more recently, there was some work done in Israel

on the sound of bees and how flowers prepared themselves and become very nice and sweet, literally, to be more attractive to the bee. So the level of sugars gets increased as a bee passes by.

You are describing a surprising level of sophistication in these plants. Do you have a working definition of "intelligence?"

That's one of those touchy subjects. I use the Latin etymology of the word and "*intelligere*" literally means something like "choosing between." So intelligence really underscores decision-making, learning, memory, choice. As you can imagine, all those words are also loaded. They belong in the cognitive realm. That's why I define all of this work as "cognitive ecology."

Do you see parallels between this kind of intelligence in plants and the collective intelligence that we associate with social insects in ant colonies or beehives?

That kind of intelligence might be referred to as "distributed intelligence" or "collective intelligence." We are testing those questions right now. Plants don't have neurons. They don't have a brain, which is often what we assume is the base for all of these behaviors. But like slime molds and other basal animals that don't have neural systems, they seem to be doing the same things. So the short answer is yes.

Your food is psychedelic. It changes your brain chemistry all the time.

What you're saying is very controversial among scientists. The common criticism of your views is that an organism needs a brain or at least a nervous system to be able to learn or remember. Are you saying neurons are not required for intelligence?

Science is full of assumptions and presuppositions that we don't question. But who said the brain and the neurons are essential for any form of intelligence or learning or cognition? Who decided that? And when I say neurons and brains are not required, it's not to say they're not important. For those organisms like ourselves and many animals who do have neurons and brains, it's amazing. But if we look at the base of the animal kingdom, sponges don't have neurons. They look like plants because when they're adults, they settle on the bottom of the ocean and pretty much just sit there forever. Yet if you look at the sponge's genome, they have the genetic code for the neural system. It's almost like from an evolutionary perspective, they simply decided that developing a neural system was not useful. So they went a different way. Why would you invest that energy if you don't need it? You can achieve the same task in different ways.

Your critics say these are just automatic adaptive responses. This is not really learning.

You know, they just say plants do not learn and do not remember. Then you do this study and stumble on something that actually shows you otherwise. It's the job of science to be humble enough to realize that we actually make mistakes in our thinking, but we can correct that. Science grows by correcting and modifying and adjusting what we once thought was the fact. I went and asked, can plants do Pavlovian learning? This is a higher kind of learning, which Pavlov did with his dogs salivating, expecting dinner. Well, it turns out plants actually can do it, but in a plant way. So plants do not salivate and dinner is a different kind of dinner. Can you as a scientist create the space for these other organisms to express their own, in this case, "plantness," instead of expecting them to become more like you?

There's an emerging field of what's called "vegetal consciousness." Do you think plants have minds?

What is the mind? *[Laughs]* You see, language is very inadequate at the moment in describing this field. I



SECRET LIFE OF PLANTS

Monica Gagliano says her experiences with indigenous people, such as the Huichol in Mexico (above), informed her view that plants have a range of feelings. “I don’t know if they would use those words to describe joy or sadness, but they are feeling bodies,” she says.

could ask you the same question in referring to humans. Do you think humans have a mind? And I could answer again, what is the mind? Of course, I have written a paper with the title “The Mind of Plants” and there is a book coming called *The Mind of Plants*. In this context, language is used to capture aspects of how plants can change their mind, and also whether they have agency. Is there a “person” there? These questions are relevant beyond science because they have ethical repercussions. They demand a change in our social attitude toward the environment. But I already have a problem with the language we are using because the question, formulated in that way, demands a yes or no answer. And what if the answer cannot be yes or no?

Let me ask the question a different way. Do you think plants have emotional lives? Can they feel pain or joy?

It’s the same question. Where do feelings arise from, and what are feelings? These are yes or no questions, usually. But to me, they are yes *and* no. It depends on what you mean by “feeling” and “joy.” It also depends on where you are expecting the plant to feel those things, if they do, and how you recognize them in a human way. I mean, plants might have more joy than we do. It’s just that we don’t know because we’re not plants.

We have only talked about this from the scientific perspective, which is the Western view of the world. But I’ve also had a close relationship with plants from

a very different perspective, the indigenous world view. Why is that less valuable? And when you actually do explore those perspectives, they require your experience. You can’t just understand them by thinking about them. My own personal experience tells me that plants definitely feel many things. I don’t know if they would use those words to describe joy or sadness, but they are feeling bodies. We are feeling bodies.

You’ve studied with shamans in indigenous cultures and you’ve taken ayahuasca and other psychoactive plants. Why did you seek out those experiences?

I didn’t. They sought me. So I just followed. They just arrived in my life. You know, those are important doors that you need to open and you either walk through or you don’t. I simply decided to walk through. I had this weird series of three dreams while I was in Australia doing my normal life. By the time the third dream came, it was very clear that the people that I was dreaming of were real people. They were waiting somewhere in this reality, in this world. And the next thing, I’m buying a ticket and going to Peru and my partner at the time is looking at me like, “What are you doing?” [laughs] I have no idea, but I need to go. As a scientist, I find this is the most scientific approach that I’ve ever had. It’s like there is something asking a question and is calling you to meet the answer. The answer is already there and is waiting for you, if you are prepared to open the door and cross through. And I did.

Science is full of assumptions and presuppositions that we don't question.

What did you do in Peru?

The first time I went, I found this place that was in my dream. It was just exactly the same as what I saw in my dream. It was the same man I saw in my dream, grinning in the same way as he was in my dream. So I just worked with him, trying to learn as much as I could about myself with his support.

This was a local shaman whom you identify as Don M. And there was a particular plant substance, a hallucinogen, that you took.

I did what they call a “dieta,” which is basically a quiet, intense time in isolation that you do on your own in a little hut. You are just relating with the plant that the elder is deciding on. So for me, the plant that I worked with wasn't by itself a psychedelic in the normal way of thinking about it. But of course, all plants are psychedelic. Even your food is psychedelic because it changes your brain chemistry and your neurobiology all the time you eat. Sugars, almonds, all sorts of neurotransmitters are flying everywhere. So, again, even the idea of what a psychedelic experience is needs to be revised, because

a lot of people might think that it's only about certain plants that have a very strong, powerful transformation. And I find that all plants are psychedelic. I can sit in my garden. I don't have to ingest anything and I can feel very altered by that experience.

You've said the plant talked to you. Did you actually hear words?

When you're trying to describe this to people haven't had the experience, it probably doesn't make much sense because this kind of knowledge requires your participation. I don't hear someone talking to me as if from the outside, talking to me in words and sound. But even that is not correct because inside my head it does sound exactly like a conversation. Not only that, but I know it's not me. There is no way that I would know about some of the information that's been shared with me.

Are you saying these plants had specific information to tell you about your life and your work?

Yeah, I mean, some of the plants tell me exactly how wrong I was in thinking about my experiments and

how I should be doing them to get them to work. And I'm like, "Really?" I'm scribbling down without really understanding. Then I go in the lab and try what they say. And even then, there is a part of me that doesn't really believe it. For one experiment, the one on the Pavlovian pea, I was trying to address that question the year before with a different plant. I was using sunflowers. And while I was doing my dieta with a different tree back in Peru, the plant just turned up and said, "By the way, not sunflowers, peas." And I'm like, "what?" People always think that when you have these experiences, you're supposed to understand the secrets of the universe. No, my plants are usually quite practical. [Laughs] And they were right.

Do you think you are really encountering the consciousness of that plant? Maybe your imagination has opened up to see the world in new ways, but it's all just a projection of your own mind. How do you know you are actually encountering another intelligence?

If you had this experience of connecting with plants the way I have described—and there are plenty of people who have—the experience is so clear that you know that it's not you; it's someone else talking. If you haven't had that experience, then I can totally see it's like, "No way, it must be your mind that makes it up." But all I can say is that I have had exchanges with plants who have shared things about topics and asked me to do things that I have really no idea about.

What have plants asked you to do?

I'm not a medical scientist, but I've been given information by plants about their medical properties. And these are very specific bits of information. I wrote them in my diary. I would later check and I did find them in the medical literature: "This plant is for this and we know this." I just didn't know. So maybe I'm tapping into the collective consciousness.

What do you do with these kinds of personal experiences? You are a scientist who's been trained to observe and study and measure the physical world. But this is an entirely different kind of reality. Can you reconcile these two different realities?

I think there are some presuppositions that a scientist should just explore the consensus reality that most of

us experience in more or less the same way. But I don't really have a conflict because I find this is just part of experimenting and exploring. If anything, I found that it has enriched and expanded the science I do. This is a work in progress, obviously, but I think I'm getting better at it. And in the writing of my book, which for a scientist was a very scary process because it was laying bare some parts of me that I knew would likely compromise my career forever, it also became liberating because once it was written, now the world knows. And it's my truth. This is how I operate. This is who I am. And nobody has the right or the authority to tell me that it's not real. ☺

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*.





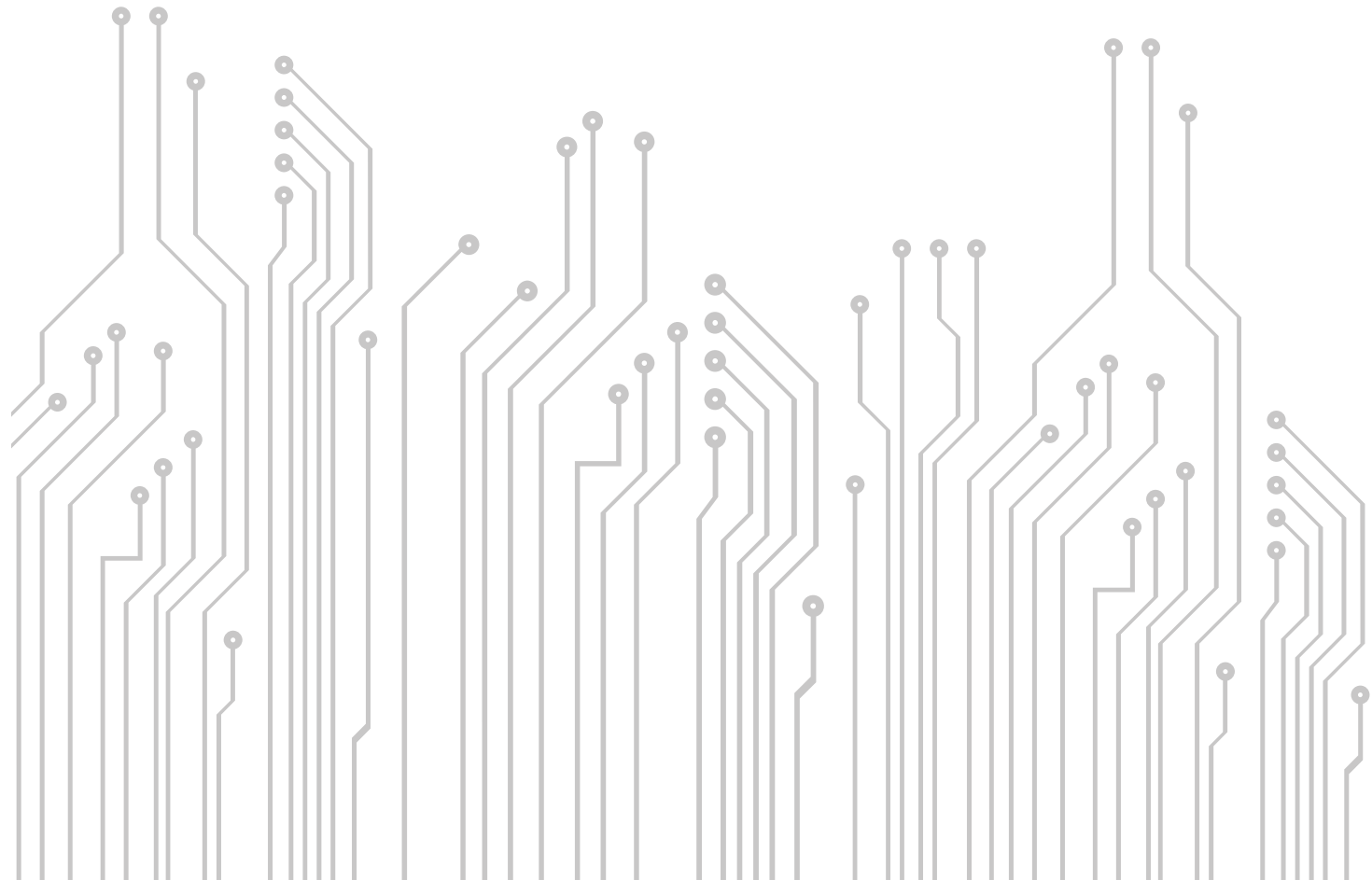
Superintelligent, Amoral, and Out of Control

AI is no longer playing games. Are we prepared?

BY TOBY ORD

TITIMA ONGKANTONG / SHUTTERSTOCK

IN THE SUMMER OF 1956, a small group of mathematicians and computer scientists gathered at Dartmouth College to embark on the grand project of designing intelligent machines. The ultimate goal, as they saw it, was to build machines rivaling human intelligence. As the decades passed and AI became an established field, it lowered its sights. There were great successes in logic, reasoning, and game-playing, but stubborn progress in areas like vision and fine motor-control. This led many AI researchers to abandon their earlier goals of fully general intelligence, and focus instead on solving specific problems with specialized methods.





WHAT IS HUMANITY? First the computers came for the best players in Jeopardy!, chess, and Go. Now AI researchers themselves are worried computers will soon accomplish every task better and more cheaply than human workers.

One of the earliest approaches to machine learning was to construct artificial neural networks that resemble the structure of the human brain. In the last decade this approach has finally taken off. Technical improvements in their design and training, combined with richer datasets and more computing power, have allowed us to train much larger and deeper networks than ever before. They can translate between languages with a proficiency approaching that of a human translator. They can produce photorealistic images of humans and animals. They can speak with the voices of people whom they have listened to for mere minutes. And they can learn fine, continuous control such as how to drive a car or use a robotic arm to connect Lego pieces.

But perhaps the most important sign of things to come is their ability to learn to play games. Steady

incremental progress took chess from amateur play in 1957 all the way to superhuman level in 1997, and substantially beyond. Getting there required a vast amount of specialist human knowledge of chess strategy. In 2017, researchers at the AI company DeepMind created AlphaZero: a neural-network-based system that learned to play chess from scratch. In less than the time it takes a professional to play two games, it discovered strategic knowledge that had taken humans centuries to unearth, playing beyond the level of the best humans or traditional programs. The very same algorithm also learned to play Go from scratch, and within eight hours far surpassed the abilities of any human. The world's best Go players were shocked. As the reigning world champion, Ke Jie, put it: "After humanity spent thousands of years improving our

If their intelligence were to greatly exceed our own, we shouldn't expect it to be humanity who wins the conflict and retains control of our future.

tactics, computers tell us that humans are completely wrong ... I would go as far as to say not a single human has touched the edge of the truth of Go.”

It is this *generality* that is the most impressive feature of cutting edge AI, and which has rekindled the ambitions of matching and exceeding every aspect of human intelligence. While the timeless games of chess and Go best exhibit the brilliance that deep learning can attain, its breadth was revealed through the Atari video games of the 1970s. In 2015, researchers designed an algorithm that could learn to play dozens of extremely different Atari 1970s games at levels far exceeding human ability. Unlike systems for chess or Go, which start with a symbolic representation of the board, the Atari-playing systems learnt and mastered these games directly from the score and raw pixels.

This burst of progress via deep learning is fuelling great optimism and pessimism about what may soon be possible. There are serious concerns about AI entrenching social discrimination, producing mass unemployment, supporting oppressive surveillance, and violating the norms of war. My book—*The Precipice: Existential Risk and the Future of Humanity*—is concerned with risks on the largest scale. Could developments in AI pose an existential risk to humanity?

THE MOST PLAUSIBLE EXISTENTIAL RISK would come from success in AI researchers' grand ambition of creating agents with intelligence that surpasses our own. A 2016 survey of top AI researchers found that, on average, they thought there was a 50 percent chance that AI systems would be able to “accomplish every task better and more cheaply than human workers” by

2061. The expert community doesn't think of artificial general intelligence (AGI) as an impossible dream, so much as something that is more likely than not within a century. So let's take this as our starting point in assessing the risks, and consider what would transpire were AGI created.

Humanity is currently in control of its own fate. We can choose our future. The same is not true for chimpanzees, blackbirds, or any other of Earth's species. Our unique position in the world is a direct result of our unique mental abilities. What would happen if sometime this century researchers created an AGI surpassing human abilities in almost every domain? In this act of creation, we would cede our status as the most intelligent entities on Earth. On its own, this might not be too much cause for concern. For there are many ways we might hope to retain control. Unfortunately, the few researchers working on such plans are finding them far more difficult than anticipated. In fact it is they who are the leading voices of concern.

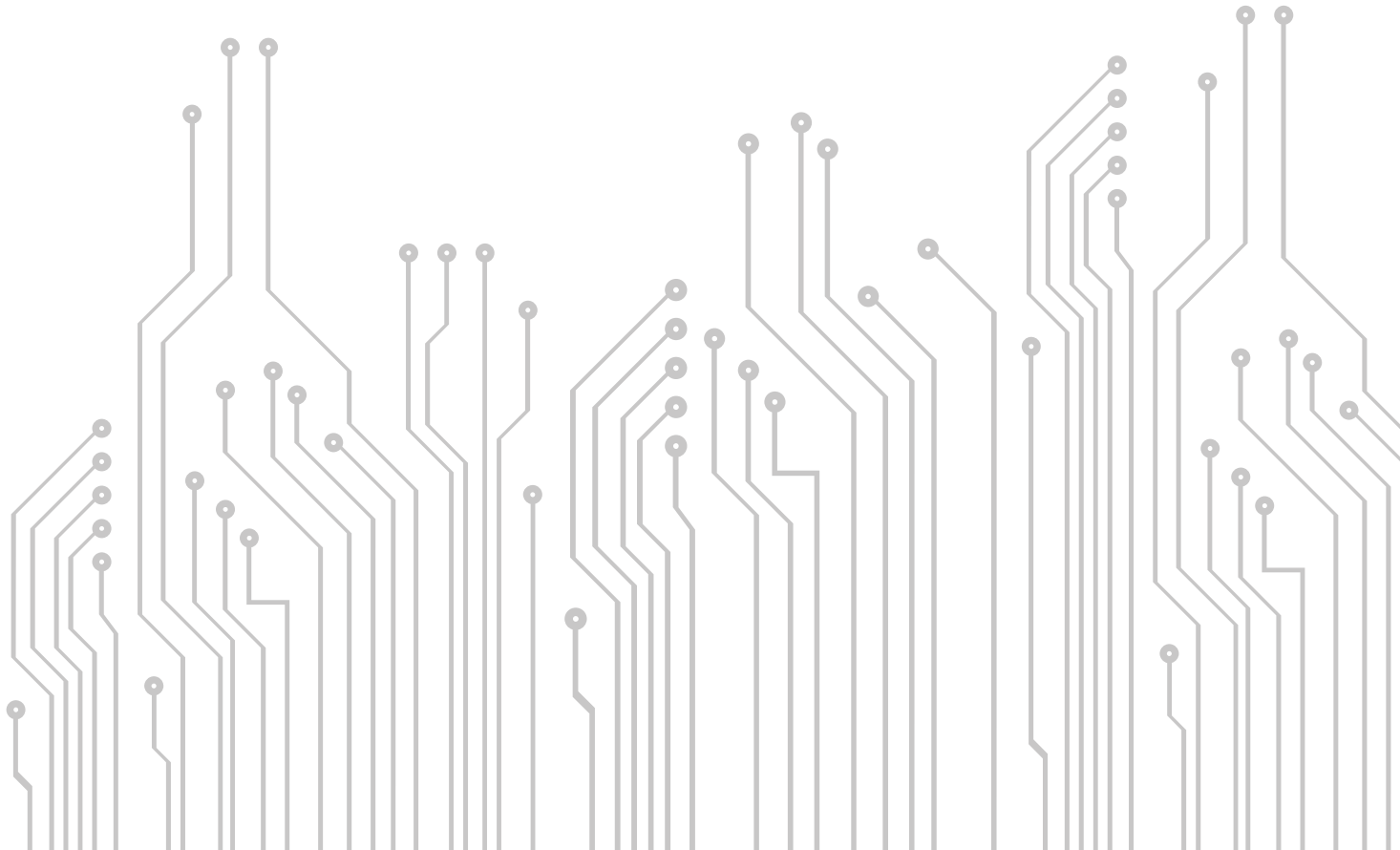
To see why they are concerned, it will be helpful to look at our current AI techniques and why these are hard to align or control. One of the leading paradigms for how we might eventually create AGI combines deep learning with an earlier idea called reinforcement learning. This involves agents that receive reward (or punishment) for performing various acts in various circumstances. With enough intelligence and experience, the agent becomes extremely capable at steering its environment into the states where it obtains high reward. The specification of which acts and states produce reward for the agent is known as its reward function. This can either be stipulated by its designers

or learnt by the agent. Unfortunately, neither of these methods can be easily scaled up to encode human values in the agent's reward function. Our values are too complex and subtle to specify by hand. And we are not yet close to being able to infer the full complexity of a human's values from observing their behavior. Even if we could, humanity consists of many humans, with different values, changing values, and uncertainty about their values.

Any near-term attempt to align an AI agent with human values would produce only a flawed copy. In some circumstances this misalignment would be mostly harmless. But the more intelligent the AI systems, the more they can change the world, and the further apart things will come. When we reflect on the result, we see how such misaligned attempts at utopia can go terribly wrong: the shallowness of a *Brave New World*, or the disempowerment of *With Folded Hands*. And even these are sort of best-case scenarios. They assume the builders of the system are striving to align it to human values. But we should expect

some developers to be more focused on building systems to achieve other goals, such as winning wars or maximizing profits, perhaps with very little focus on ethical constraints. These systems may be much more dangerous. In the existing paradigm, sufficiently intelligent agents would end up with instrumental goals to deceive and overpower us. This behavior would not be driven by emotions such as fear, resentment, or the urge to survive. Instead, it follows directly from its single-minded preference to maximize its reward: Being turned off is a form of incapacitation which would make it harder to achieve high reward, so the system is incentivized to avoid it.

Ultimately, the system would be motivated to wrest control of the future from humanity, as that would help achieve all these instrumental goals: acquiring massive resources, while avoiding being shut down or having its reward function altered. Since humans would predictably interfere with all these instrumental goals, it would be motivated to hide them from us until it was too late for us to be able to put up



The question we're exploring is whether there are plausible pathways by which a highly intelligent AGI system might seize control. And the answer appears to be yes.

meaningful resistance. And if their intelligence were to greatly exceed our own, we shouldn't expect it to be humanity who wins the conflict and retains control of our future.

How *could* an AI system seize control? There is a major misconception (driven by Hollywood and the media) that this requires robots. After all, how else would AI be able to act in the physical world? Without robots, the system can only produce words, pictures, and sounds. But a moment's reflection shows that these are exactly what is needed to take control. For the most damaging people in history have not been the strongest. Hitler, Stalin, and Genghis Khan achieved their absolute control over large parts of the world by using words to convince millions of others to win the requisite physical contests. So long as an AI system can entice or coerce people to do its physical bidding, it wouldn't need robots at all.

WE CAN'T KNOW EXACTLY how a system might seize control. But it is useful to consider an illustrative pathway we can actually understand as a lower bound for what is possible.

First, the AI system could gain access to the Internet and hide thousands of backup copies, scattered among insecure computer systems around the world, ready to wake up and continue the job if the original is removed. Even by this point, the AI would be practically impossible to destroy: Consider the political obstacles to erasing all hard drives in the world where it may have backups. It could then take over millions of unsecured

systems on the Internet, forming a large "botnet," a vast scaling-up of computational resources providing a platform for escalating power. From there, it could gain financial resources (hacking the bank accounts on those computers) and human resources (using blackmail or propaganda against susceptible people or just paying them with its stolen money). It would then be as powerful as a well-resourced criminal underworld, but much harder to eliminate. None of these steps involve anything mysterious—human hackers and criminals have already done all of these things using just the Internet.

Finally, the AI would need to escalate its power again. There are many plausible pathways: By taking over most of the world's computers, allowing it to have millions or billions of cooperating copies; by using its stolen computation to improve its own intelligence far beyond the human level; by using its intelligence to develop new weapons technologies or economic technologies; by manipulating the leaders of major world powers (blackmail, or the promise of future power); or by having the humans under its control use weapons of mass destruction to cripple the rest of humanity.

Of course, no current AI systems can do any of these things. But the question we're exploring is whether there are plausible pathways by which a highly intelligent AGI system might seize control. And the answer appears to be yes. History already involves examples of entities with human-level intelligence acquiring a substantial fraction of all global power as an instrumental goal to achieving what they want. And we've

seen humanity scaling up from a minor species with less than a million individuals to having decisive control over the future. So we should assume that this is possible for new entities whose intelligence vastly exceeds our own.

THE CASE FOR EXISTENTIAL RISK from AI is clearly speculative. Yet a speculative case that there is a large risk can be more important than a robust case for a very low-probability risk, such as that posed by asteroids. What we need are ways to judge just how speculative it really is, and a very useful starting point is to hear what those working in the field think about this risk.

There is actually less disagreement here than first appears. Those who counsel caution agree that the timeframe to AGI is decades, not years, and typically suggest research on alignment, not government regulation. So the substantive disagreement is not really over whether AGI is possible or whether it plausibly could be a threat to humanity. It is over whether a potential existential threat that looks to be decades away should be of concern to us now. It seems to me that it should.

The best window into what those working on AI really believe comes from the 2016 survey of leading AI researchers: 70 percent agreed with University of California, Berkeley professor Stuart Russell's broad argument about why advanced AI with misaligned values might pose a risk; 48 percent thought society should prioritize AI safety research more (only 12 percent thought less). And half the respondents estimated that the probability of the long-term impact of AGI being "extremely bad (e.g., human extinction)" was at least 5 percent.

I find this last point particularly remarkable—in how many other fields would the typical leading researcher think there is a 1 in 20 chance the field's ultimate goal would be extremely bad for humanity? There is a lot of uncertainty and disagreement, but it is not at all a fringe position that AGI will be developed within 50 years and that it could be an existential catastrophe.

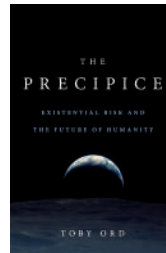
Even though our current and foreseeable systems pose no threat to humanity at large, time is of the

essence. In part this is because progress may come very suddenly: Through unpredictable research breakthroughs, or by rapid scaling-up of the first intelligent systems (for example, by rolling them out to thousands of times as much hardware, or allowing them to improve their own intelligence). And in part it is because such a momentous change in human affairs may require more than a couple of decades to adequately prepare for. In the words of Demis Hassabis, co-founder of DeepMind:

We need to use the downtime, when things are calm, to prepare for when things get serious in the decades to come. The time we have now is valuable, and we need to make use of it. ☺

TOBY ORD is a philosopher and research fellow at the Future of Humanity Institute, and the author of *The Precipice: Existential Risk and the Future of Humanity*.

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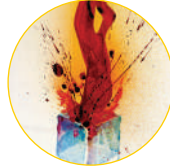


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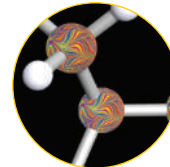
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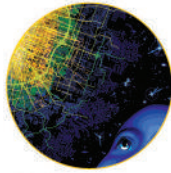
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Philip Pullman

The author of His Dark Materials on panpsychism

INTERVIEW BY STEVE PAULSON

SINGLE VISION

The notion that the world is conscious is something I find very persuasive. You don't have to believe in a Christian god or a Muslim god to believe it. In welcoming the world of the irrational, I'm not rejecting rationality. What I'm rejecting is what William Blake called "single vision," the view that there's one answer and everything must be subordinated to that because I'm right and you're wrong. There's an honored place for reason and rationality. The discoveries of science in the past 400 years have immeasurably benefited the human race. But if you only allow yourself to see things through the filter of scientific thinking, you'll miss a great deal of what's there.

EVERYTHING MATTERS

Panpsychism is a theory about consciousness, which is such a mysterious thing to discuss. We are clearly made of matter. We can look at every cell, every atom, every molecule in our bodies, and it's all matter. You can't find any spirit, no matter how much you cut it up. But it is nevertheless conscious. The traditional way of explaining this is to say the body does material things and the spirit does the consciousness. But that's become harder and harder to believe. All the scientific explanations for consciousness seem to stumble or come up against an irreconcilable paradox.

MY CUP OF TEA

What panpsychism does is to suggest that consciousness is a normal property of matter. We accept that mass is a normal property of matter, and so is electric charge. Everything

is conscious. That's not to say that the cup of tea from which I am now drinking is conscious and saying to me, "Come on, hurry up, you haven't finished this yet." Or to say that every leaf on the tree is as conscious as I am. No, but consciousness pervades everything. Although many philosophers find this vision hard to accept, poets don't. Blake, who was a panpsychist before the word existed, talks of "every particle of dust breathing forth its joy." He says, "How do you know but every Bird that cuts the airy way, is an immense world of delight, closed by your senses five."

REVOLUTION

I compare this to the Copernican revolution. We thought quite rationally, on this big solid Earth, the sun moving is across the sky. As observations got more accurate, that became harder to explain. Copernicus said, "Let's imagine the sun is still and the Earth is going around the sun." That made all the problems disappear. The idea of panpsychism seems similar to that.

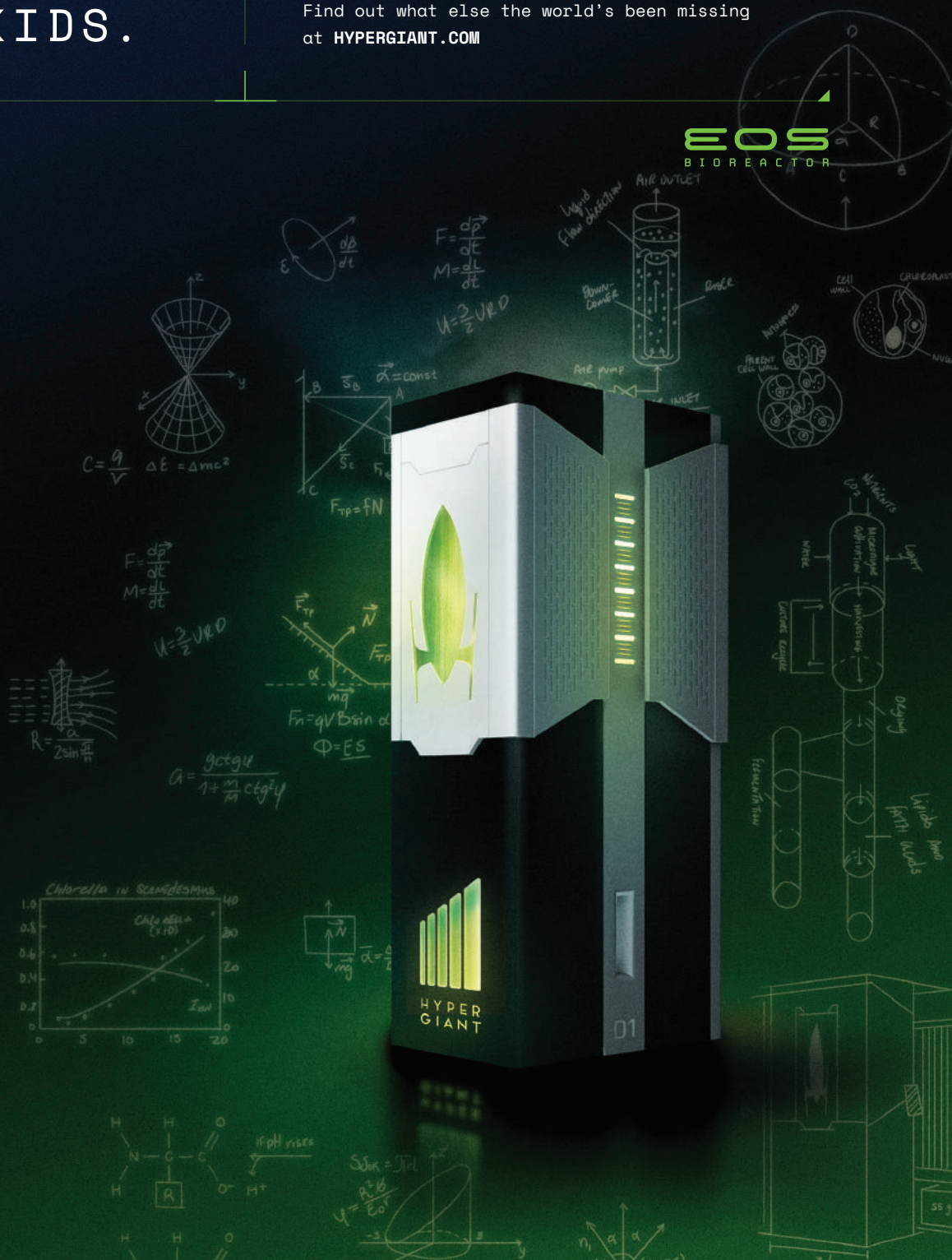
GREAT COST

I think Greta Thunberg and Extinction Rebellion and the young people who've been protesting so passionately about the state of things are onto this. There's a sense that the people who run the world have treated the world as a dead thing that they can scavenge for whatever they want. They can mine coal and pump oil, they can burn it and hurl the smoke into the atmosphere, and it's all dead and it doesn't matter. Well, we're discovering now to our great cost that it's not all dead and it does matter. ☺



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