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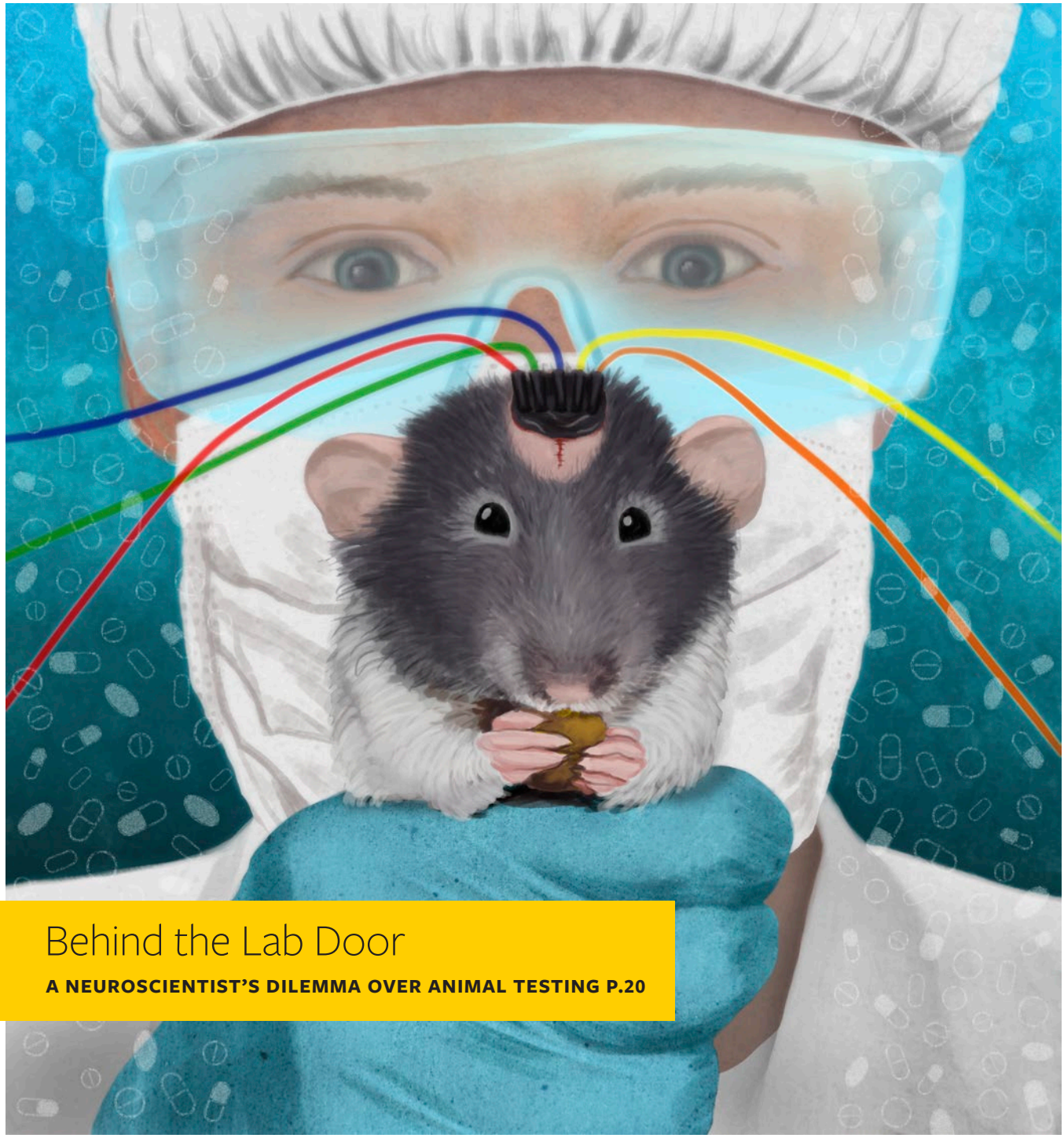

Behind the Lab Door

A NEUROSCIENTIST'S DILEMMA OVER ANIMAL TESTING P.20

EARTH'S BIGGEST PROBLEM ISN'T GOING TO SOLVE ITSELF.

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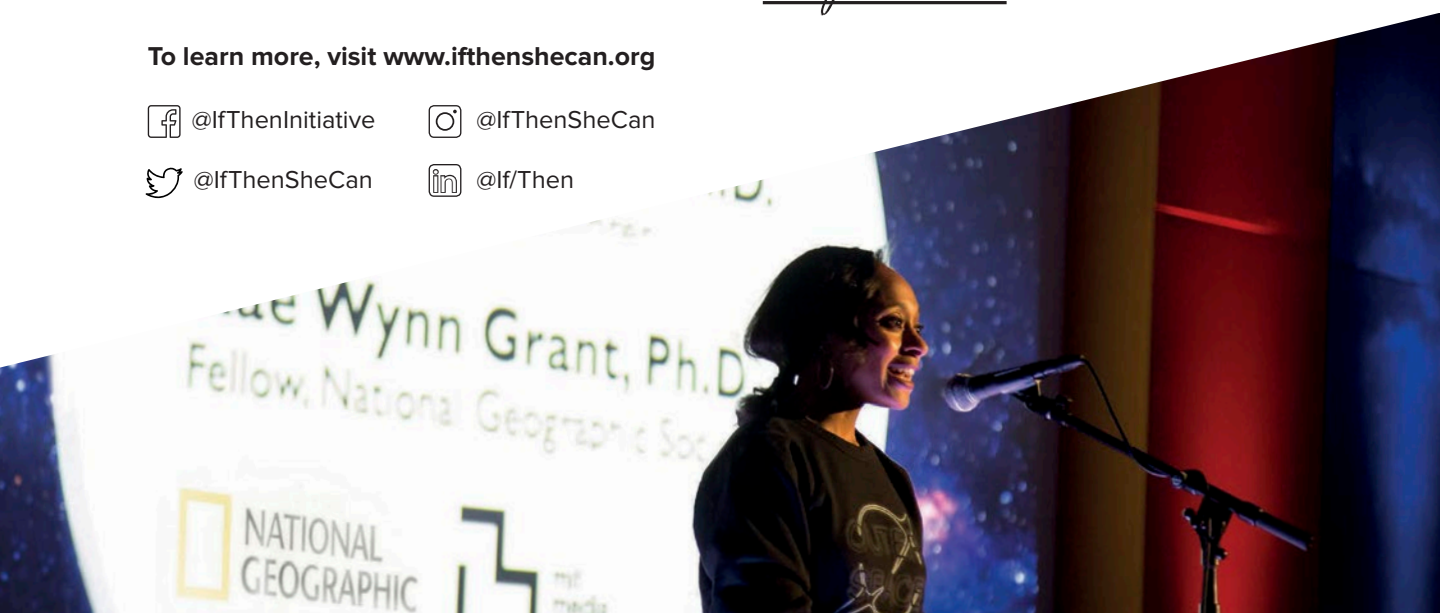

Features

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The Renewal of Science

BY KEVIN BERGER

NOT LONG AGO I was in a dank catacomb, listening to the Creature from *Frankenstein* bemoan his loneliness. I was at the Green-Wood Cemetery in Brooklyn. The catacomb, a narrow stone corridor, was host to an opera recital, *Sketches from Frankenstein*, by composer Gregg Kallor. At the end of the catacomb, singer Joshua Jeremiah, a lumbering man with a bone-rattling baritone, embodied the Creature. With a spectral piano and cello for accompaniment, the melancholy Creature pleaded for Victor Frankenstein to create him a mate. "Oh, my creator, let me be loved," he sang. "By someone. By something. Just once."

The moving performance reminded me of the emotional depths of *Frankenstein*, a quality nearly forgotten in Mary Shelley's evocation of fear and longing at the dawn of industrial science. *Frankenstein* is so often read as an allegory of scientific hubris that its poetry and complexity have all but been obscured by images of mushroom clouds and cloned babies. Shelley didn't write an admonition against playing God. She wrote a story about people losing their soul. If *Frankenstein* is a cautionary tale, it is about science losing its humanity.

That tension runs through this issue's cover story, "Are Animal Experiments Justified?" by neuroscientist Grigori Guitchounts. Guitchounts offers readers a rare firsthand account of what goes on behind lab doors. "Keeping sentient beings confined, operating on and killing them, is difficult for me, and doesn't square with my love of animals," he writes. It's not giving away the story to say Guitchounts' quest to resolve his personal dilemma doesn't end well for the rats. But the humanity in his story shows us science continues to progress in its treatment of animals.

While Shelley had more on her mind than humans playing God, she tapped into a repulsion that still curdles people today. In "Scientists Should Play God," Tania Lombrozo, a professor of psychology at Princeton University, reports that religious people are not alone in feeling humans shouldn't tinker with "the natural order." But while the moral aversion to playing God hinders progress in science, Lombrozo explains, donning the mantle of a deity has advanced beneficial technologies.

Where technology gets worrisome is in the hands of autocrats. In "WeChat Is Watching," Barclay Bram, an Oxford University Ph.D. candidate stationed in China, shares his daily experiences with the omnipresent WeChat app and the constant hum of paranoia it generates. The original idea of the Internet was to enhance democracy, before it became overrun by advertising and "reinforced political echo chambers," report the authors of "Six Degrees of Separation at Burning Man." But the article, recounting the authors' own social-science experiment at Burning Man, is not another jeremiad, it is a revelation that "cooperation doesn't have to be forced on us, it can come from within us."

Like every issue of *Nautilus*, our stories upend clichés. Frankenstein is not the monster created by Hollywood. Nor is science. In the lab and the field, it's the human practice that dissolves illusions and allows us to see nature anew.


Every extinction is a tragedy.
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Readers Respond

Comments and letters about stories from print issue 26.

"HOW WE'LL FORGET JOHN LENNON"

I was intrigued by the claim that "athletes last longer than songs, movies, and science papers." It seems counter-intuitive—old songs and movies are relatively easily accessible, but old sports games are rarely aired, and in most cases before about 1970 are no longer even fully extant.

—James Kabala

"IT'S THE END OF THE GENE AS WE KNOW IT"

There are interesting things in this article—but a revealing absence of references to studies of separated twins. Those studies long ago showed that genetic identity counts for a great deal, although environment has a powerful modifying effect as well. The "blank slate" ideological polemic shines through all too often.

—David Laney

I'm in no way an expert on the science of DNA. With that said, it has long been known that the chromosomes are modified based on "external" factors such as what is learned through nurturing and environment (adaptation to climate, food sources, immunity, etc). Could it be that here we are just finding out more about how those modifications come about, resulting in "evolution?"

—Maurice Rogerson

"THE MATH THAT TAKES NEWTON INTO THE QUANTUM WORLD"

This is a wonderful essay—it is delightful to see a mathematician so passionate about a very deep (to many inscrutable) mathematical topic. It also takes us to the edges and corners of the conundrum that is mathematics. Is it all connected in some grand way? It it discovered or created?

—George Gantz

"WHY THE BRAIN IS SO NOISY"

A lot of people see the brain as a big complex neural network, which when you compare it to an AI program, makes the AI look completely incompetent. However, I see a biological brain as a really amazing orchestra of many different neural networks. And similarly, an intelligent AI will likely not be one program, but an advanced metaprogram that runs a number of complex subroutines emulating neural networks.

Looking at an AI program and saying "see, this is not intelligent" is like an alien plucking out the wernicke area of a human brain and saying "look, this biological computer is not intelligent, it only understands one language."

Overall awesome article, lots of insights to what elements will be added to AI programs of the future.

—Dr. Brando

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

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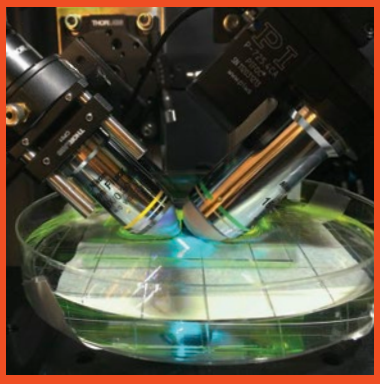

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Preludes

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LINGUISTICS

The English Word That Hasn't Changed in 8,000 Years

The word *lox* was one of the clues that led linguists to discover who the Proto-Indo-Europeans were.

ONE OF MY FAVORITE words is *lox*," says Gregory Guy, a linguistics professor at New York University. There is hardly a more quintessential New York food than a lox bagel—but Guy is passionate about lox for a different reason. "The pronunciation in the Proto-Indo-European was probably 'lox,' and that's exactly how it is pronounced in modern English," he says. "Then, it meant salmon, and now it specifically means 'smoked salmon.' It's really cool that that word hasn't changed its pronunciation at all in 8,000 years and still refers to a particular fish."

How scholars have traced the word's pronunciation over thousands of years is also really cool. The 18th-century British polymath Thomas Young noticed eerie similarities between Indic and European languages. He analyzed 400 languages spread across continents and millennia and proved that the overlap between some of them was too extensive to be an accident. In 1813, he declared that all those languages belong to one family, and named it "Indo-European."

Today, roughly half the world's population speaks an Indo-European language—well over half of all modern English words are borrowed from other languages. And linguists have developed ingenious strategies to trace how language changes. "Some parts of vocabulary are more stable and don't change as much. These are numbers, colors, family relations like 'mother,' 'father,' ... and basic verbs like 'walk'

and 'see,' " says Guy. "If you look at words of that sort in different languages, it becomes fairly clear which ones are related and which ones are not. For example, take the English word night, which is *nacht* in German and *noch* in Russian."

Analyzing the patterns of change that words undergo when they move from one language to another showed how to unwind these changes and identify the possible originals. "You collect words that mean more or less the same thing in all the languages, and if they look like each other in terms of their pronunciation, then it's a good candidate for a descendant from a common ancestor," explains Guy.

After discovering a word that might have existed in the Indo-European, linguists compared how its pronunciations changed from language to language. For example, sound [k] changes to [h] from Latin to Germanic, and the Latin word *casa* transforms into the English *house* while the French word *cœur* transforms into the English *heart*. With hints like that, linguists could trace the original pronunciation. In several thousand years, most words change beyond recognition, but there were some remarkable exceptions—like the timeless *lox*.

The family tree of the Indo-European languages sprawls across Eurasia, including such different species as English and Tocharian B, an extinct language once spoken on the territory of Xinjiang in modern China. In Tocharian B, the word for "fish/salmon" is *laks*, similar to German *lachs*, and Icelandic *lax*—the only ancestor all these languages share is the Proto-Indo-European.

The word *lox* was one of the clues that led linguists to discover who the Proto-Indo-Europeans were, and where they lived. The fact that those distantly related Indo-European languages had almost the same pronunciation of a word meant that word likely existed in the Proto-Indo-European language. "If they had a word for it, they must have lived in a place where there was salmon," explains Guy. "Salmon is a fish that lives in the ocean, reproduces in fresh water and swims up to rivers to lay eggs and mate. There are only a few places on the planet where that happens."

In reconstructed Indo-European, there were words for *bear*, *honey*, *oak tree*, and *snow*, and no words for *palm tree*, *elephant*, *lion*, or *zebra*. Using clues like that, linguists could deduce the only possible place these people could have called home—a narrow band between Eastern Europe and the Black Sea where animals, trees, and insects matched the ancient Indo-European words. In the 1950s, archaeologists uncovered remnants of an ancient culture that lived there from 6,000 to 8,000 years ago.

Back then, the grassy steppes that run from Western China to the Black Sea had large herds of wild horses, which most early humans hunted. The Proto-Indo-Europeans were probably the first people to domesticate the ancestors of modern-day horses. That brought them an enormous advantage, allowing them to move a lot faster than any other human group. Then, they attached those horses to wheeled vehicles. "That's probably the moment when they suddenly managed to expand into the Middle East, into India, and across Europe," says Guy. "Within the next thousands of years, they expanded like no other human group that we know of in history. Because they had mobility, which nobody else had."

—Sevindj Nurkiyazova

EVOLUTION

What an Extinct Bird Re-Evolving Says About "Species"

YOU MAY HAVE HEARD the news of what sounds like a resurrection story on the small island of Aldabra, off the coast of Madagascar. Around 136,000 years ago, the island was submerged in water and a layer of limestone captured the rails—a species of flightless bird—living there. The birds (and all other land species living on the island) went extinct. Recently, though, scientists reported that the bones of these fossilized rails are virtually indistinguishable from rails living on the island today. They are calling this an instance of iterative evolution—where the same species evolves multiple, distinct times.

How could the same species evolve more than once? Both the fossil and modern rail are descendants of flying rails that made their way to Aldabra from the nearby mainland. And each time, the species gradually lost its ability to fly, possibly due to a lack of predators on the island (which removes a significant selection pressure for flight). This raises an interesting question: Can birds on different branches of the evolutionary tree really be part of the same species? The answer depends on what you mean by "species." As it turns out, it is difficult (and some would argue, impossible) to conceptualize species in a way that fully, and without exception, captures what it is that makes a group of organisms one species and not another.

If we rewound the universe to the origins of life, would evolution produce the same species we see today?

Most biologists prefer what is called the biological species concept, meaning organisms of the same species must be able to interbreed to produce viable offspring. This concept does not apply to many plants and most microorganisms, though, because they reproduce asexually. Even for sexually reproducing animals it is often difficult in practice to determine whether two groups of organisms could potentially interbreed. The Aldabra rails give a case in point since the fossil rails are, well, fossils.

I should point out that the authors actually call the flightless rail *D. c.* subsp. *aldabranus*—a *sub*species of *Dryolimnas cuvieri*. But this just pushes the problem a step back—what makes them the same subspecies? The authors' comparison between the fossil and modern rail is based on the shape and size of fossilized bones. This points to what is called the morphological species concept, which demarcates species based on similarity between bodily structures.

But this conflicts with what the phylogenetic species concept—probably the second most-used of the species concepts—would tell us. In this conception, a species is the smallest group of organisms that share an ancestor and can be grouped together based on some core characteristics, like the end of a branch on a tree of life. On the phylogenetic species concept, the fossil rails and modern rails are different subspecies, since by dint of having split off from the mainland, rail species at different times, they have independent evolutionary origins. The modern rail is part of a different lineage than the fossil rail.

Part of the motivation for calling these the same subspecies based on morphology is that the bones of the fossil and modern rail are more similar in size than either is to their close ancestors. It would probably make most biologists that favor the phylogenetic species concept happy to say instead that these are two extremely similar subspecies. But the fact that these rails are so similar that the question of species distinction even arises is a reflection of something even more fascinating.

This reappearance is a near-perfect example of a thought experiment evolutionary biologist Stephen Jay Gould imagined—what he called "replaying life's tape." He wondered about the repeatability of evolution—if we rewound the universe to the origins of life, would evolution produce the same species we see today?

JANOS RAUTONEN / SHUTTERSTOCK

This question has surfaced again as scientists study an evolutionary phenomenon called convergence. Most examples of convergence—like the camera eye possessed by both humans and octopuses—can be called horizontal, meaning they involve organisms with distant evolutionary relationships who ended up in adaptively similar environments and evolved similar traits. But these flightless birds are a case of *vertical* convergence—possibly one of Stephen Jay Gould's wildest dreams.

As the authors write, because of the environmental conditions, "a Dryolimnas rail was able to evolve flightlessness independently on each occasion." The tape resets when the island reemerges with much the same environmental conditions as before and the mainland rail species recolonizes. It replays to reach the same (or, if you prefer, *very similar*) subspecies.

—Margaret E. Farrell

PHILOSOPHY

Can Neuroscience Understand Free Will?

IMAGINE THAT AN ECCENTRIC BILLIONAIRE has offered you a deal: If you merely *intend* to drink a toxin tonight that will make you painfully ill for a day, he will wire you $1 million—it'll be in your bank tomorrow morning. A sophisticated and reliable brain scanner will determine whether you really formed the intention to imbibe the toxin. After you have the money, you're free to decide not to drink it. An easy way to become a millionaire, no? Just intend to drink it for the scanner and, once you have the cash, switch your intention. This delightful head-scratcher comes from a 1983 paper, "The Toxin Puzzle," by Gregory Kavka.

This is absurd, of course, and that's Kavka's point: We don't have that sort of control over ourselves. If you intend to drink it but also intend, later, to not drink it, you're really intending to not drink it. "One cannot intend whatever one wants to intend any more than one can believe whatever one wants to believe." says Kavka. The sense that you have of being in control, of having free will, is just that—a sense. And it can break.

Neuroscientists have identified some of the brain networks responsible for this sense of free will. There seems to be two: the network governing the desire to act, and the network governing the feeling of responsibility for acting. Brain-damaged patients show that these can come apart—you can have one without the other.

Lacking essentially all motivation to move or speak has a name: akinetic mutism. A team led by neurologists Michael Fox and Ryan Darby analyzed 28 cases of this condition, not all of them involving damage in the same areas. "We found that brain lesions that disrupt volition occur in many different locations, but fall within a single brain network, defined by connectivity to the anterior cingulate," which has links to both the "emotional" limbic system and the

> The sense of freedom we have to act on our moral understanding is regulated and vulnerable, and can break.

"cognitive" prefrontal cortex, they wrote. Feeling like you're moving under the direction of outside forces has a name, too: alien limb syndrome. The researchers analyzed 50 cases of this condition, which again involved brain damage in different spots. "Lesions that disrupt agency also occur in many different locations, but fall within a separate network, defined by connectivity to the precuneus," which is involved, among other things, in the experience of agency.

The results may not map onto "free will" as we understand it ethically—the ability to choose between right and wrong. "It remains unknown whether the network of brain regions we identify as related to free will for movements is the same as those important for moral decision-making," the researchers wrote.

The concept of free will doesn't make any sense to me. As Kavka's thought experiment shows, we don't have much control over our thoughts. Take this article I'm writing: The words I'm committing to print pop into my mind unbeckoned. It's less me choosing them and more them presenting themselves to me. The act of writing feels more like a process of passive filtration than active conjuration. I'm also convinced that humans can sensibly hold one another morally responsible even if we jettison the idea of free will. The reason is that, as a social mechanism, it has salutary effects. Generally, if people know that they will be held to account for moral violations, they will be less likely to commit them; and if they don't know what the moral rules are, they will be motivated to learn them.

In any case, the mystery of free will isn't going away anytime soon. In March, a group of neuroscientists and philosophers announced that they've received $7 million to study the nature of free will and whether humans have it. Uri Maoz, a computational neuroscientist at Chapman University, is leading the project. "As a scientist, I don't know what it entails to have free will," he said in an interview with *Science*. That's a philosophical puzzle. But once Maoz's philosopher colleagues agree on a definition, he can get to work to see if it occurs in humans.

—Brian Gallagher

NEUROSCIENCE

The Neural Similarities Between Remembering and Imagining

IMAGINE A LIVING ROOM. Not a familiar one, but one purely from your imagination—perhaps your ideal living room. You should have no trouble doing it: We take this kind of imagination for granted. Rarely do we find ourselves wondering how the mind chooses what objects to put into these novel scenes and which ones to exclude. But it's worth reflecting on, because our visual imagination appears to be constrained by regularities in visual memories. Diversifying what you see may mean enriching what you can imagine.

In a May 2019 study neuroscientist Eleanor Maguire compared people imagining novel scenes to people imagining single objects. She found that different parts of the brain were implicated when imagining a scene compared to a single object. One is the hippocampus, which is important for both consolidation of long-term memory and the imagination. Spatial navigation and planning both rely on the hippocampus and depend on the ability to create coherent spatial scenes. One hypothesis is that the closer you perceive things to be to each other—a couch and a coffee table, for instance—the more likely you are to later put them into an imagined scene. This suggests that, as you create a scene, your brain starts a feedback loop between the hippocampus and the visual cortex.

The other is the ventromedial prefrontal cortex (vmPFC), which plays a role in deliberation and self-control. Maguire found that the vmPFC was quite active while subjects imagined scenes, but was less so while they imagined objects. She also found that it was activated *before* the hippocampus. This suggests that the hippocampus takes instructions from the vmPFC for how a scene should look—and this is what happens when you recall a memory.

Diversifying what you see may mean enriching what you can imagine.

In my laboratory, we try to model this kind of imagination in software. My graduate students and I made an imagination engine to imagine scenes the same way people do. We would give it a prompt word, like "mouse," and it would find objects in its database, or the words for them, that tend to appear in photographs with mice. The engine would then put five things associated with a mouse in an imagined scene. We quickly encountered a problem: The engine, given the word "mouse," would generate both a cat and a computer keyboard. People don't do this—they just pick objects associated with one meaning of the term.

My graduate student Michael Vertolli sought to solve this problem using co-occurrence, which, in the context of a spatial scene, is similar to proximity. He had our imagination engine look not only at the correlation between the prompt word and a retrieved object, but also at the correlations among the retrieved objects. "Computer keyboard" co-occurs with "mouse," but it doesn't appear in the same photographs as mousetraps. So one of them would be swapped out for a different word. This would repeat until all of the objects in the imagined scene correlated with each other. In the human brain, different regions of the hippocampus appear to have different functions—the CA3 subregion gets input for memory, and this is fed into the CA1 subregion, which scientists suspect detects coherent patterns.

What might seem unintuitive about this is that, when you imagine a visual scene, it doesn't feel like things are being replaced one by one. Apparently we are not conscious of the candidates our minds reject for placement in a scene—we are only privy to the things that end up there.

It's long been common knowledge that imaginings are re-combinations of bits from memory. But now we're seeing that the act of recalling something that happened to you looks very much like what happens when you imagine something new.

—Jim Davies

HBRH / SHUTTERSTOCK

SCIENCE PRACTICE

Our Aversion to A/B Testing on Humans Is Dangerous

FACEBOOK ONCE TEAMED UP with scientists at Cornell to conduct a now-infamous experiment on emotional contagion. Researchers randomly assigned 700,000 users to see a slight uptick in either positive or negative language, or no change at all, on their News Feeds for one week, to determine whether exposure to certain emotions could, in turn, cause a user to express certain emotions. The answer was yes: The emotions we see expressed online can change the emotions that we express, albeit slightly. However, the public disclosure of the study sparked an intense backlash against what many saw as an unjust and underhanded manipulation of people's feelings. Facebook would later apologize for fiddling

with users' emotions and pledge to revise its internal review practices.

Yet there's reason to think the backlash wasn't entirely reasonable. The magnitude of the researchers' manipulation was small; what users saw on their altered feeds wasn't much different, if at all, from what they would normally see. What's more, Facebook had universally implemented a radical change in the way people express themselves, with unknown effects on mental well-being, in merely launching their platform, said Michelle Meyer, an assistant professor of bioethics at Geisinger Health System.

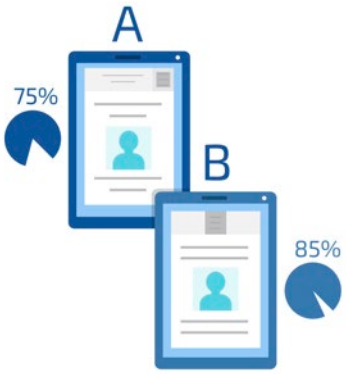
Facebook's emotional contagion study is just one example of businesses trying to better understand their products and services via randomized experiments, or "A/B tests"— experiments in which subjects are randomly assigned to receive one of two different treatments and then compared. Like the emotional contagion study, many of these experiments caused public outcry for reasons that may seem intuitive and obvious, such as the lack of informed consent, or the idea that it's wrong to knowingly treat people unequally. But a recent series of studies from Meyer and her colleagues casts doubt on these explanations. Their research suggests that people have an irrational aversion to A/B tests, which could limit the extent to which important institutions like hospitals, legislatures, and corporations base their decisions on objective evidence.

Across 16 studies, Meyer and her colleagues randomly assigned 5,873 participants to read vignettes of a leader deciding how to achieve a goal. The leader could land on one of three decisions: to universally implement one policy, to universally implement another policy, or to conduct an A/B test to compare the two before choosing one. Participants were randomly assigned to see one of the three possible decisions and rate its appropriateness. Importantly, for each topic, neither of the untested policies was obviously better than the other.

People preferred those in power to universally implement untested policies at their discretion instead of testing them.

Meyer and her team found that in nearly every situation they tested, the decision to conduct an A/B test was deemed least appropriate by a considerable margin. In other words, people preferred those in power to universally implement untested policies at their discretion instead of testing them. This "A/B effect" held up even in participants with a STEM education or with high levels of scientific literacy.

When asked to justify their ratings, many participants expressed concern that the decision-makers never asked people for consent before conducting tests on them. Yet the issue of consent was raised by less than 1 percent of the participants who got a vignette where the leader universally implemented an untested policy. This puzzled Meyer and her colleagues because, as they wrote, "in all cases, people were subjected without their consent to one of the same two untested policies with unknown effects." Why were the A/B tests singled out?



One possible cause of the A/B effect, according to the researchers, is the "proxy illusion of knowledge," or the belief that other people know more than they actually do. Participants may have found it unsettling to see people in power admit a need to conduct tests—in other words, that they don't know enough. "It makes you feel a little safer, a little more comfortable in your day-to-day, to imagine the director of the hospital where you're being treated is omniscient, or knows what's going to work," said Patrick Heck, a co-author of the paper. "When in fact that's quite rarely the case."

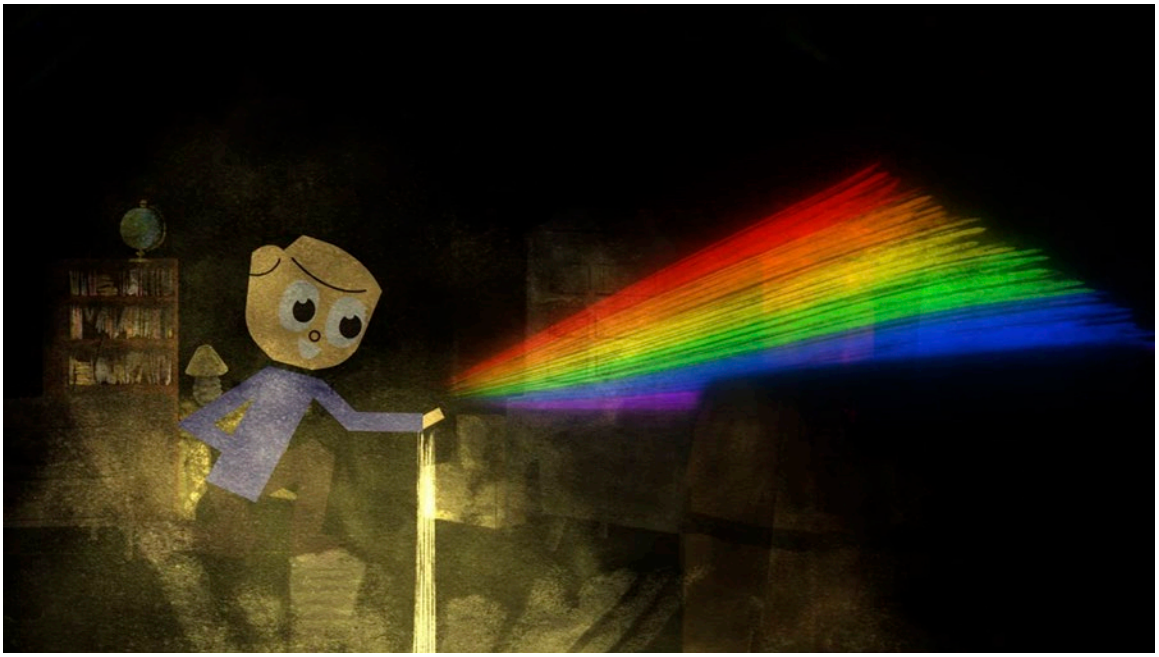
It may also be that A/B tests are off-putting because of the cultural baggage associated with science and experimentation. "From the Nazis to Tuskegee to human vivisection to *Frankenstein*—most of which, by the way, were not actual scientific experiments," said Meyer, "there's a colloquial use of the word 'experiment' and also 'random' that has very negative connotations."

Whatever the cause, there seems to be a persistent distaste for A/B tests across much of the population. Meyer, Heck, and their team are now focusing on finding ways to make A/B tests more palatable.

—Scott Koenig

ANDRII SYMONENKO / SHUTTERSTOCK

His Spark of Science



I HAD THIS FRIEND. We both went to school. And we'd been through the motions. But at 3 o'clock when school was finished, life started. So we'd go either to his place or my place, and we'd both have these attics full of stuff. It was just like one big lab. And it was so natural. Nobody told me this. It's the germ that led to everything. I always feel that I can trace back whatever I did to these beginnings. I remember we made it totally pitch dark, and we had a little space, and the sunlight was going in, and putting these prisms and of course creating a rainbow, lenses. It's just magical. Because you're eight years old, you're holding a rainbow in your hand. That's a kind of feeling of empowerment. There's this wonderful phrase, I think John Wheeler phrased it as "magic without magic." It's a magical phenomenon but you're not being tricked. It's the real thing. You're unveiling the magic that's in the world. In many ways, life adds a lot of extra weight. You're traveling with all these suitcases or something. But I think you have to go back. For me, always in my life, it's very important to go back to what's the origin of your passion.

—Robbert Dijkgraaf, Director and Leon Levy Professor, Institute of Advanced Study, Princeton University

ILLUSTRATION BY JOSHUA JOUPPI

Are Animal Experiments Justified?

A neuroscientist confronts his anguish over experimenting on animals

BY GRIGORI GUITCHOUNTS

THE RAT SAT STILL in the middle of her cage, moving only in response to my touch, and even then only as if in slow motion. My subject, GRat66, was a few months old, and except for her long bare tail, fit neatly into my palm a few minutes earlier, when I injected a few drops of a potent opiate under her skin, near the belly. Now, her beady black eyes bulged as she faded into an opiate stupor.

I was preparing to implant minuscule electrodes into the rat's brain. The opiate would serve as an analgesic before, during, and after the surgery. It was the fall of 2018 and I was hoping the results of the surgery would help answer some questions that had been tormenting me as I embarked on the sixth year of my Ph.D. in neuroscience. How do the parts of the brain controlling movement interact with those responsible for visual sensation? Why do neurons in the visual areas jolt to action when an animal moves, even in the dark?

I placed GRat66 into an anesthesia-induction chamber, a small plastic box connected to a vaporizer that dispenses the anesthetic, isoflurane. After she was sufficiently knocked out (I pinched her toes to make sure the withdrawal reflex was gone), I placed her into a stereotax, which serves to hold the head steadily in place and provides a flow of isoflurane into her body throughout the operation. I then injected a half a milliliter of lidocaine under the rat's scalp, which swelled with the local anesthetic's volume. Dressing myself in a sterile gown, facemask, and gloves, I proceeded to cut across the length of GRat66's scalp, exposing the thick ivory-colored skull underneath the pink and bloody skin and shiny white fat.

Peering through a microscope, I drilled a small hole in the skull using a dental drill and carefully peeled back the membrane covering the brain. I positioned the electrodes—wires 10 times thinner than a human hair—over one of the visual areas and lowered them slowly into the brain. I then secured the electrodes with glue and closed the wound. At the end of the four-hour procedure, the top of the rat's head was replaced by a chef's hat full of electronics that would transmit data from the brain to my computer via a thin tether. I added some finishing touches of glue, squeezing the viscous off-white cement onto the margin between the scalp and the implant, and turned off the anesthetic, letting GRat66 wake up slowly over the following hour.

PHOTOS BY THE AUTHOR

Isn't freedom more valuable than painlessness, even to a rat?

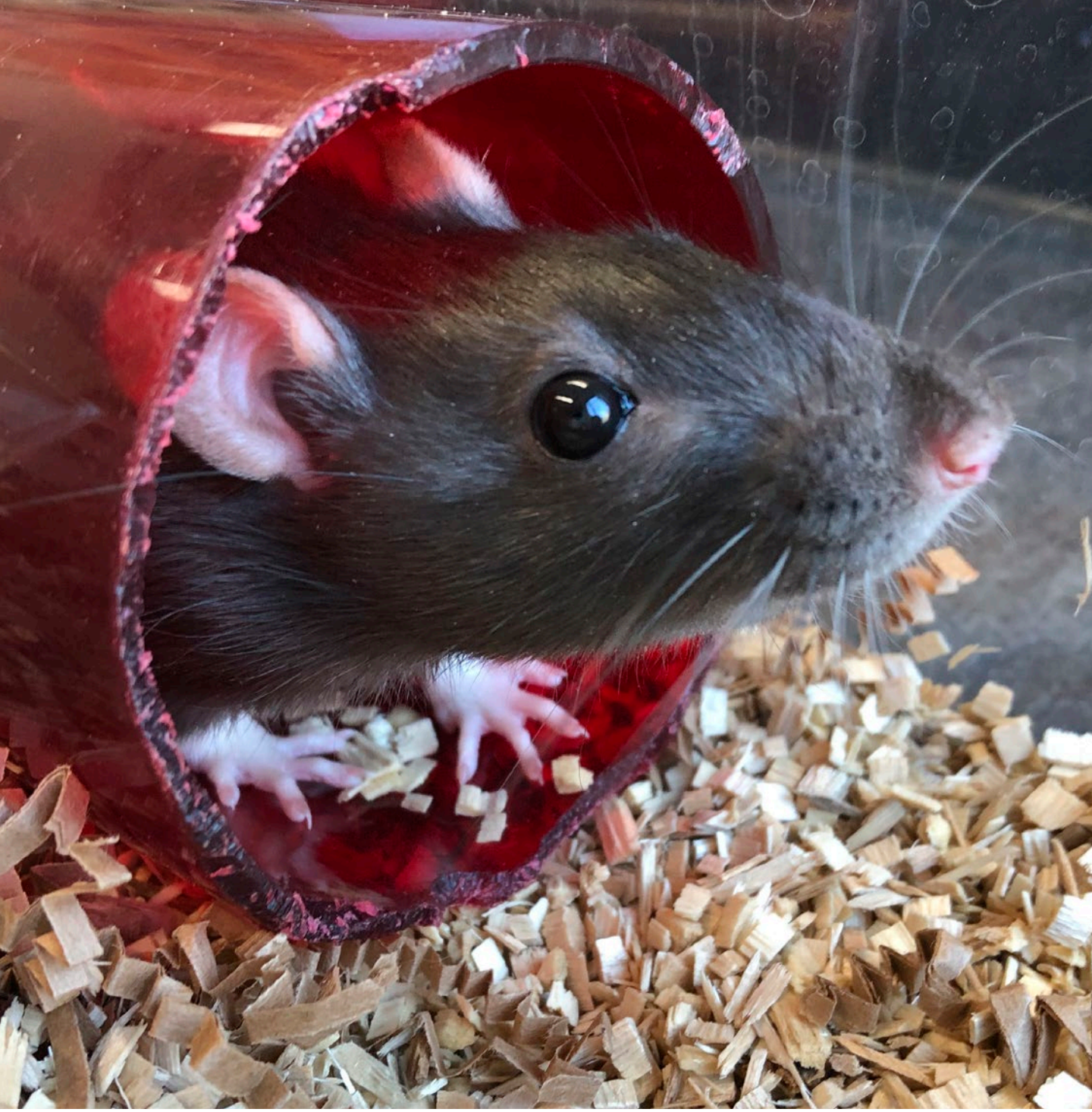
Scientists do basic research for the sake of knowledge. When reminded that that knowledge has costs, they usually offer a utilitarian argument: The benefits to humanity outweigh the harm done to animals, whose lives have less value than human ones. The picture gets more complicated on the level of individual experiments: If basic science is done for the sake of knowledge, and we don't know how informative or useful the outcome of an individual animal experiment will be, how can we justify doing it?

Research on animals has delivered many benefits to humanity. It has given us anesthesia, antibiotics (penicillin was discovered in petri dishes, but its properties and safety were verified in mice), vaccination, and therapies for Parkinson's disease. The neurotransmitter serotonin, the indirect target of many antidepressants, was found in animal brains by the biochemist Betty Twarog, in 1953. Diphenhydramine, a muscle-relaxing agent initially discovered in research on dogs, was later shown to quell allergy symptoms (brand names include Benadryl), and still later was modified into Prozac.

Scientists try to use previously acquired knowledge and models rather than animals in their studies whenever possible. But our understanding of brains is so rudimentary that attempting to gain more knowledge without studying actual brains would be like trying to solve a crossword puzzle in an unknown foreign language. We won't be able to produce treatments for bodies if we don't know how those bodies work.

Still, I'm torn. Keeping sentient beings confined, operating on and killing them, is difficult for me, and doesn't square with my love of animals. I know a miraculous solution to my quandary is unlikely, but I hope there might be something I can do to ensure the moral balance of my actions leans toward the good. Then, last year, I stumbled on an intriguing project at the Massachusetts Institute of Technology Media Lab called "Reducing Suffering in Laboratory Animals." Led by geneticist Kevin Esvelt, this research promised to "develop strains of mice that experience far less pain and suffering than current animals." I sought Esvelt out, curious if his work could help resolve my dilemma.

ESVELT GREETED ME at his office at the MIT Media Lab on a humid fall afternoon. He is the principle investigator of the Sculpting Evolution group, a lab that uses the latest in molecular and genetic tools to understand evolutionary processes. Currently, Esvelt is creating



WHAT'S GOING ON? A rat in Grigori Guitchounts' lab peeks out of a plastic tube to investigate and sniff the neuroscientist taking her photo.

PLAY TIME Grigori Guitchounts supplies his lab rats with plenty of playthings, like crinkled cardboard paper, in which they burrow and nest.

genetically modified mice that are insensitive to physical pain. A trim 36-year-old with blond hair, Esvelt was dressed in a blue button-down shirt, dark pants, and sandals (no socks). His intense blue-eyed gaze betrayed what I diagnosed as hyper-caffeination. "I'm actually very concerned about animal well-being in general," he told me. "We engineer mice all the time. Why on Earth do we not genetically engineer mice so it is easier to turn off their perception of pain and thereby reduce suffering?"

Esvelt was inspired by Geoffrey Woods, a geneticist at Cambridge University in the United Kingdom who has studied rare cases of people insensitive to physical pain. In a 2006 paper, Woods and an international team of researchers reported genotyping results from three Pakistani families with pain-insensitive children. The scientists homed in on the families after someone in the local medical community observed the behavior of a 10-year-old boy who performed in the streets by putting knives through his arms. He died before his 14th birthday, "after jumping off a house roof," they wrote in their paper, published in *Nature*.

After sequencing the genomes of several children from these families, the scientists found a mutation in *SCN9A*, the gene that encodes the sodium channel Nav1.7, a protein pore that allows charged sodium ions to flow into a neuron, charging it like a battery. Creatures with mutations of *SCN9A* are normal in almost every respect: They have reasonable intelligence, they can see, hear, coordinate their movements, and feel touch. If someone sticks a pin through their skin, they will feel the mechanical displacement (they might report that something is touching them), but won't have any idea that the sensation is painful or harmful.

While the relationship between genes and perception is mind-numbingly complex in most cases, mutations of *SCN9A* have clear effects. "You knock out this particular receptor and you don't feel any mechanical pain whatsoever," Esvelt told me. "We have human testimony to that. That's the one we know we can do. And we could have done this, frankly, a long time ago."

While a pain-insensitive lab mouse would be unlikely to jump off a building, having no idea what pain is throughout its life would be a maladaptive trait. To get around this problem, Esvelt and his graduate student Devora Najjar, who joined us in Esvelt's office later, decided to harness novel genetic tricks that would enable them to induce a knockout of *SCN9A* whenever they choose, essentially putting a switch on pain sensitivity. This could be done by adding a specific molecule to the mice's diet, which would prevent neurons from making the sodium channel Nav1.7 for as long as the mice eat the laced chow; after finishing the experiments, the researchers could put the animals back on the normal diet, allowing their genetic machinery to start making Nav1.7 as before.

It's "important that when the mice grow up, they develop normal pain-sensing behaviors because it prevents them from developing bad habits like chewing on their tongues or getting into fights," Esvelt said. "You want them to grow up experiencing pain normally and then turn it off just before you're going to do the experiment."

I asked Esvelt if having painless mice might, paradoxically, lead to more suffering. A mouse that can't feel pain might earn less respect from researchers. Najjar, a fast-talking Long Islander, echoed my concern. "People might do more unethical experimentation with

an animal that can't feel any pain," she said. To avoid this, she proposed leveraging the existing protections that lab animals enjoy; the idea would be to have these painless mice remain categorized as if they were normal animals, except that instead of opiates, they would receive their analgesia via Esvelt's genetic engineering.

While we now understand pain well enough to turn it off, I left MIT wondering if the painless mouse project missed some of the point of what constitutes suffering. My rats wouldn't feel a whole lot of pain throughout my experiments, thanks to the opiates I give them before and after surgery, and yet it's hard to believe they don't suffer. They spend their entire lives in a shoebox-sized cage, in solitary confinement for a large chunk of that time. They have toys, shelter, and unlimited food. Those benefits, though, don't seem to make up for their imprisonment and invasive surgery. Isn't freedom more valuable than painlessness, even to a rat?

THAT PEOPLE CARE about lab animal well-being is heartening, and the fact that the animals have any protections at all is not trivial. It wasn't always so. Like much of human history, the history of animal experimentation is one of gruesome cruelty. In the pursuit of knowledge, entertainment, or profit, humans have inflicted unimaginable suffering upon billions of animals over centuries.

Human curiosity about animal physiology led the ancient Greeks and Romans to perform vivisections—surgery on awake, kicking, squealing animals. Galen of Pergamum, a Greek physician living in Rome, described his vivisections around A.D. 177 in a volume called *On Anatomical Procedures*. For the purpose of brain or spinal cord surgery, he wrote, "you must procure either a pig or a goat." A pig or goat was preferable to an ape because "you avoid seeing the unpleasing expression of an ape when it is vivisected." Next, Galen advised, stretch the animal out on a board with holes for straps and secure its limbs; then, procure a large strong knife.

I don't believe that I have an inalienable right to do research on animals.

"Every cut that you impose should travel in a straight line," Galen wrote, "and the cut should without pity or compassion penetrate into the deep tissues in order that with a single stroke you may lay free and uncovered the skull of the animal." After peeling the scalp away and cutting through the skull, you are ready to start your experiment. "You can first of all press down upon the brain on each one of its four ventricles, and observe what derangements have afflicted the animal." Thus, in the crudest possible terms, the study of the brain was born. In a way, that is how neuroscience is

HEART OF THE DILEMMA "Almost everyone I know who does basic biological research loves animals and has pets," a senior scientist tells the author.

still conducted today: Observe the brain, manipulate it, and see what happens to behavior as a result.

With the rise of Christianity, which preached that God made animals for humans' use, attitudes toward animals grew bleak. French philosopher Rene Descartes wrote that responses to painful stimuli in animals are merely reflexes, and that animals are not capable of any internal experience because they don't have souls. To this vacuous view, Voltaire delivered a devastating response about a century later. "Barbarians seize this dog, which in friendship surpasses man so prodigiously," Voltaire wrote in his *Philosophical Dictionary*, in 1764. They "nail it on a table, and dissect it alive in order to show the mesenteric veins," only to "discover in it all the same organs of feeling that are in yourself ... Has nature arranged all the means of feeling in this animal, so that it may not feel?" Modern science has validated the great thinker's rhetorical question, providing an overwhelming multitude of evidence that animals, from mice to macaques, robins to ravens, do feel pain and can suffer, physically and emotionally.

By the late 19th century, some of the experiments done on animals were done under anesthesia, which was discovered and refined in the first half of that century. But it took another hundred years before people started caring about the well-being of animals outside the surgical context. In 1966, the United States Congress passed the Laboratory Animal Welfare Act, which required licensing of labs and animal dealers, inspections of facilities by the U.S. Department of Agriculture, and sufficient postoperative analgesia to be given to animals. Later instantiations of the Welfare Act have

established institutional animal care and usage committees that consist of veterinarians, laypeople, and others tasked with ensuring the best possible care of lab animals.

As laws began to change, so too did public concern for animal suffering. The biggest bombshell was the publication of Peter Singer's *Animal Liberation* in 1975. The book contains nightmarish descriptions of cruel experiments (such as the ones that induce learned helplessness in dogs by delivering inescapable electric shocks), and offers a bleak view of the scientific enterprise. "Among the tens of millions of experiments performed, only a few can possibly be regarded as contributing to important medical research," Singer wrote. "Experiments serving no direct and urgent purpose should stop immediately, and in the remaining fields of research, we should, whenever possible, seek to replace experiments that involve animals with alternative methods that do not."

I had heard much praise for the book in my college days, but hadn't read it until last year. I was startled by Singer's dismissal of the utility of basic science and wondered if his views had evolved in the more than 40 years since the book was published. I was curious too what Singer would make of Esvelt's painless mice, and so I called him.

"I'm not going to deny that some experiments on animals have yielded benefits for humans," Singer offered, cautiously. Over the phone, I immediately recognized the dry, dispassionate tone that made the arguments of *Animal Liberation* so devastating. Singer admitted that if an animal experiment could "cure some major disease that causes an immense amount of suffering," and it was shown there was no other way to reach that cure, and the animals wouldn't suffer in the experiment, "I would be prepared to say, 'OK, the use of animals was justifiable under those conditions.'"

But what about basic biomedical research and the quest for knowledge? Would animal experiments be justified in that case? "If we're talking about basic research rather than something that's curing a disease, then it's much harder to answer that question," he said. "Maybe eventually basic research will have some sort of spinoff in terms of helping us to overcome some condition we have. But from my perspective, simply gaining knowledge for its own sake does not justify inflicting

I drilled a small hole in the skull and carefully peeled back the membrane covering the brain.

significant amounts of suffering on animals. You need to tell how this could ultimately lead to some important breakthroughs which would be good for sentient beings, humans or animals."

Singer was more positive about Esvelt's painless mice. "Given that mice are going to be used in situations that would cause them physical pain, would it be good to genetically engineer mice who are insensitive to physical pain? If you put it that way, then I think the answer is pretty clearly yes," he said. He cautioned that Esvelt's painless mice could still be upset, depressed, unhappy, frightened, or anxious. Plus, experimenters might feel it's OK to do experiments that would be unjustifiable in normal mice, not recognizing that Esvelt's genetically modified mice could experience other kinds of trauma. "So it's possible that there's actually more total suffering going on than there would have been if the painless mice didn't exist at all."

I was uneasy with Singer's reluctance to allow basic research to proceed if we don't know what its impact will be. Allowing only "promising" experiments to proceed misses the fact that by its nature basic research is unpredictable, making it nearly impossible to know which experiments will yield useful results. Only in hindsight do some experiments look more promising than others.

Animal Liberation characterized scientists as oblivious and caring little for animal well-being, but this was not how I had thought of myself or my fellow researchers. I needed a different perspective, so I returned to the place my graduate education started, Harvard Medical School, wondering if a seasoned scientist could help me make sense of what had made me uneasy about Singer's philosophy. I sought out Rick Born, a professor of neurobiology, who has been working on the primate visual system since the early 1990s, asking how neurons in the visual cortex process incoming stimuli and are influenced by the vast connections from higher-level cortical areas.

BORN IS KNOWN among graduate students as a dedicated mentor, not to mention a cycling enthusiast and open-ocean swimmer. I visited him at the Medical School's Department of Neurobiology on a frosty morning in November. Entering the building that houses the department requires a Harvard ID, but primate labs exercise extra security for fear of would-be animal liberators. As I waited by the lab's locked front door, the fit 56-year-old with sparkling silver hair floated down a long corridor to let me in.

She won't encounter a lot of physical pain, but neither will she experience the joy of parenting or bonding with a mate.

We chatted in Born's office, which he shares with his bicycle. He got right to the point. "I don't believe that I have an inalienable right to do research on animals—it's something that I believe is justified by the knowledge that we gain and the benefits to society," he said. Born was personally motivated, he told me, by family and friends who suffered and had died from neurodegenerative diseases.

Born's own work on the primate visual cortex centers on basic scientific questions but also has applications for brain-machine interfaces and neural prosthetics. His team is testing a micro-coil device that delivers information into the brain via electrical signals; rhesus macaques, the monkeys Born works with, are one of the few species with the "high-resolution vision necessary to test whether such devices could substitute for natural vision," he explained.

"Almost everyone I know who does basic biological research loves animals," Born said. "And part of the reason we do this research is because we're fascinated by animals, fascinated by how brains have evolved, or fascinated with how different brains and different organisms solve the same problems. We are curious about these animals, we love them. Almost everyone I know has pets." But the fact remains that such curiosity, in the form of basic research, has costs. "We clearly do harm to the animals," Born continued. "We deprive them of their freedom. We do surgical procedures on

them." And while the standard of care in primate surgeries in the lab is on par with human procedures, "anyone who's had surgeries knows that it's not the most pleasant thing in the world."

And therein lies the conundrum: While modern technology has greatly reduced painful experiences of many lab animals, does that allow scientists to use them as we please? "I don't believe that there's a philosophical *a priori* answer to say whether we can do this or not," Born said. "It's a value judgment on the part of society. And it's a discussion that society needs to have with itself."

I left Born's office and walked down the corridor, following a technician wheeling a cart full of apple slices and grapes. As he squeezed through the door into the primate facility, I caught a glimpse of the macaques jumping up and down in their wireframe cages, hooting and shrieking excitedly at the prospect of an afternoon snack.

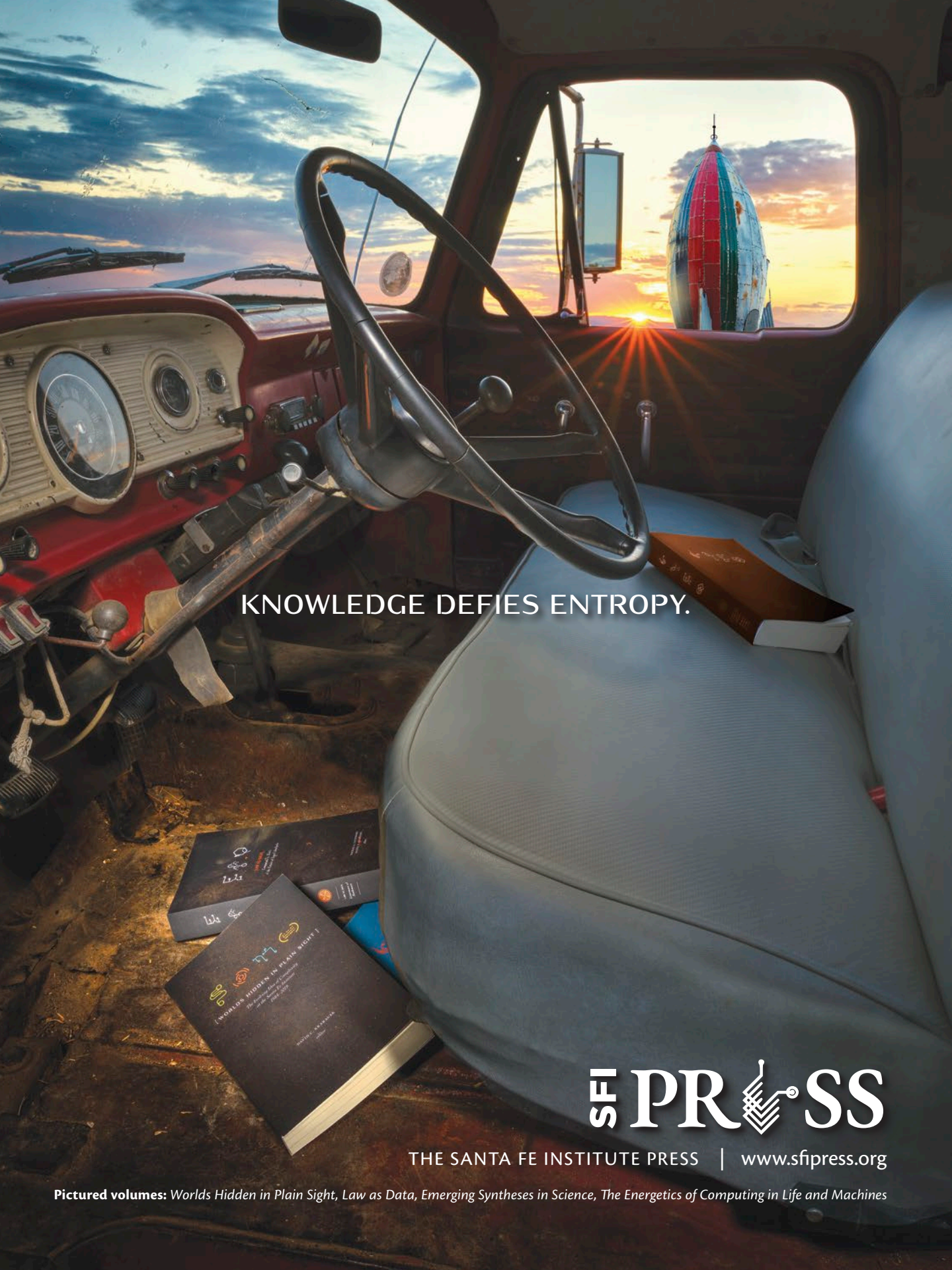
BASIC SCIENCE IS a gamble. You do experiments without knowing what will pan out and what won't. During my Ph.D., my efforts have amounted to an interesting scientific result, which is that there is a lot more information about movement in the visual parts of a rat's brain than was previously known. I think that data is worth the animal lives because every bit of knowledge firms up our foundation of basic brain processes. It's possible my data may one day provide foundational knowledge to scientists trying to cure a disease or engineers creating visual prosthetics.

Still, I can't deny that I feel uneasy. Genetically engineering rodents to feel no pain probably isn't the answer. Who is that painlessness for? The animals or us? Maybe society will have that discussion with itself and one day decide that animal experimentation should be outlawed, or perhaps strike a better balance between animal care and inquisitive basic research. For now, I can't let my emotions interfere with my work. I have to be clear-eyed and focused to make sure the animals receive the best care possible during the experiments. I try to minimize their suffering in whatever way I can.

As for GRat66, it is not likely she will encounter a whole lot of physical pain in her lifetime, but neither will she experience freedom, the joy of parenting, or bonding with a mate. The opiate, lidocaine, and isoflurane all serve to keep her from facing the horrors of past vivisections. And yet, the whole ordeal must be a nightmare to her. A cumbersome piece of plastic has replaced the skin on the top of her head. She can't see it, so in the first day after the surgery, whenever she moved too close to the water spout, she bumped up against it with her implant, unable to figure out why something was preventing her from running forward as she intended. She acclimated to it soon enough, and then, after about a week, the recordings began. For the rat, this meant that there was now a thin wire snaking up out of the electronics on her head, tethering her to a computer much like a string connects a child's hand to a balloon.

Currently, GRat66 has shelter, food, plenty of peanut butter, and not even an inkling of what it's like to live out in a "real world" full of predators who might eat her at any moment. After the recording, she will have a peaceful few months while I analyze her data. At the end, though, I will need one last thing from GRat66, to verify if the experiment was successful. That thing is her brain, and I will kill her for it.

GRIGORI GUITCHOUNTS is a neuroscientist.



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Scientists Should Play God

The aversion to interfering in a natural order is hindering progress

BY TANIA LOMBROZO

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LAST NOVEMBER CHINESE SCIENTIST He Jiankui announced the birth of twin babies whose germline he claimed to have altered to reduce their susceptibility to contracting HIV. The news of embryo editing and gene-edited babies prompted immediate condemnation both within and beyond the scientific community. An ABC News headline asked: "Genetically edited babies—scientific advancement or playing God?"

The answer may be "both." He's application of gene-editing technology to human embryos flouted norms of scientific transparency and oversight, but even less controversial scientific developments sometimes provoke the reaction that humans are overstepping their appropriate sphere of influence. The arrival of the first IVF baby in 1978, for example, was denounced as playing God with human reproduction[1]; more than 8 million "IVF-babies" have been born since.[2] As we face a global climate crisis, an article at Religion News Service questions whether proposed climate fixes based on geoengineering are playing God with the climate system.[3] For many, the idea that mere humans can or should interfere in lofty natural or human domains, whether it's the earth's climate or human reproduction, is morally repugnant.

Where does this aversion to playing God come from? And might it present an obstacle to scientific and technological advance?

A paper published in March in the *Philosophical Transactions of the Royal Society B* is the first to systematically investigate aversion to playing God and link it to negative attitudes toward science and technology.[4] Across seven experiments involving over 3,500 participants recruited within the United States, psychologists Adam Waytz, of Northwestern University, and Liane Young, of Boston College, found that judgments of "playing God" predict more restrictive views of technology use and more limited support for science.

In their first study, they found that the more a scientific procedure (such as genetic testing during pregnancy or cloning humans) is taken to involve "playing God," the more likely it is to be judged morally unacceptable. A second study found a similar relationship for drone warfare, vaccination in childhood, the production of genetically modified organisms, and the use of technologies that contribute to climate change: The more an individual thought the issue involved playing God, the more morally unacceptable they judged it to be.

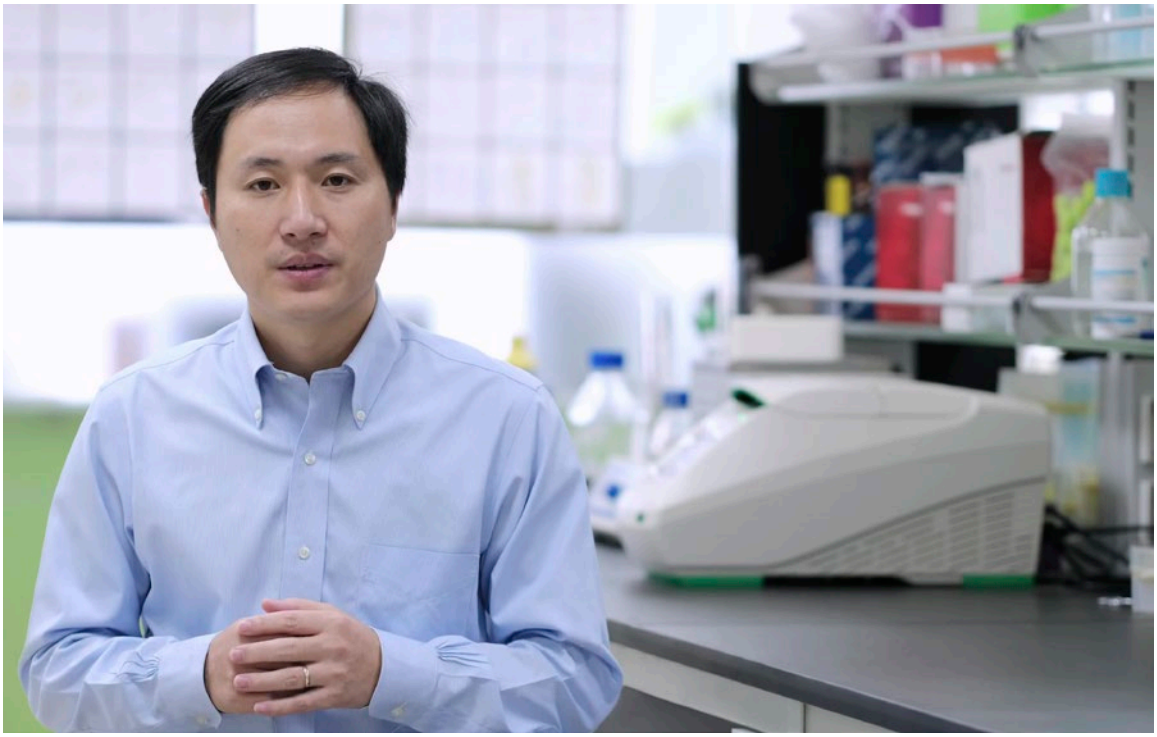
Most people don't like to think of themselves as just another mammal among many.

The researchers also found that individuals tend to vary in their level of "aversion to playing God," and that this variability relates to more general attitudes toward science. Participants who endorsed one statement of aversion to playing God (for example, "it bothers me when people try to take on the role of God") were not only more likely to endorse others (like, "there are some matters in the world that are beyond the sphere of human influence"), but were also more likely to support lower levels of funding for the National Science Foundation. Importantly, the pattern of correlations observed in this study (and all others) was not simply a reflection of participants' political ideology, religiosity, or belief in God.

Waytz and Young argue that, at least in some cases, aversion to playing God and negative attitudes toward science and technology are not only correlated, but related causally, where the former drives the latter. They also argue that aversion to playing God could hinder progress in areas such as reproductive technology, medicine, robotics, and artificial intelligence, where rapid technological advances are pushing the boundaries of what humans can achieve. This aversion could result in restrictions to research on gene editing in humans—which could prevent disease—or discourage the widespread adoption of artificially intelligent agents in decision-making roles that could improve the efficient and equitable distribution of resources. This makes it pressing to understand what underlies aversion to playing God. Is it something we can change? Is it something we *should* change?

It could be that aversion to playing God is simply a matter of people's beliefs about the existence of God and God's appropriate sphere of influence. But if not, what's really behind it?

The data reported by Waytz and Young suggest that judgments about "playing God" and "belief in God" are *not* the same, at least in this American, and largely Christian, sample. While aversion to playing God was strongly and significantly correlated with belief in God in most of their studies, this association did not fully explain the link between aversion to playing God and negative judgments regarding technology and science. More telling, analyses of additional data from two nationally representative samples, with a total of over 2,800 participants, revealed that, of the 2 to 3 percent



WIKIMEDIA

VICTOR FRANKENSTEIN, WE PRESUME He Jiankui, a scientist in Shenzen, China, who used CRISPR to alter the embryonic genes of twin girls born in 2018, is one of the most recent high-profile cases of a scientist condemned for playing God.

of respondents who indicated that they did not believe in God, 35 to 49 percent still expressed some or strong agreement with the claim that "human beings should respect nature because it was created by God." Playing devil's advocate doesn't have much to do with the devil these days; similarly, playing God—and a sense for what's considered to fall within God's sphere—might not have much to do with God.

Rather than reflecting a specific commitment to God, Waytz and Young suggest that aversion to playing God reflects "an aversion to human agency in a domain in which another agent is thought to be responsible." For some people, that "agent" could be nature. In fact, one of their studies revealed a significant (though modest) relationship between aversion to playing God and belief in a "natural order."

Yet this still leaves us with the puzzle of what drives aversion to scientific and technological intervention or change, whether it impinges on God's authority or on some natural order: Why not celebrate human agency, and rejoice in greater control over the natural world? Answering this question takes us well beyond the data, but two hypotheses are worth a look.

First, it could be that aversion to playing God is a "moral heuristic," as proposed by legal scholar and behavioral economist Cass Sunstein: a moral shortcut or rule of thumb that's useful in many contexts, but that can also lead us astray. For instance, it could be that intervening in highly consequential but highly complex, nonlinear systems is especially risky, because we can't generally be trusted to have a good handle on the likely consequences. This heuristic could be a good

guiding principle in everyday life, even if it fails to apply to contemporary science.

If this moral heuristic is what underlies aversion to playing God, it could be important for people to appreciate the discontinuities between our everyday experience of bumbling about the world, and the much more sophisticated resources of our best-developed scientific practices and theories. It also makes it important to appreciate when our scientific understanding is—and especially when it *isn't*—adequate to the task of evaluating the risks of, say, gene drives, a means of rapidly spreading new traits in a population. On this view, even if gene drives "could help solve some of humanity's greatest ecological and public health problems," as a paper published in May put it, some aversion to playing God might be warranted—but only if there's a good correspondence between our intuitive aversion to playing God and what we really do and don't know about the natural world.[5] Most people are unlikely to obtain that kind of correspondence.

A second hypothesis is that playing God could have the ironic consequence of placing us above the natural order in one sense, yet locating us firmly within it in another. To play God when it comes to human reproduction or human cloning, for example, we have to regard the very processes that make us human as susceptible to the same scientific approach that helps us build bridges and grow corn. And most people don't like to think of themselves as just another mammal among many, let alone another multicellular organism, or another object. This reflects a belief in "human exceptionalism," and it's thought to help explain resistance[6] to what Charles Darwin called our "lowly origin."

Research also suggests that it might be unsettling to think of ourselves as falling fully within the scope of science. In a set of psychological studies with my former Ph.D. student Sara Gottlieb, we found that people were happy to embrace the idea that science could one day provide complete explanations for some aspects of the human mind, such as motor control or depth perception.[7] But when it came to other psychological phenomena, such as altruistic behavior, romantic love, or belief in God, people were less likely to consider a complete scientific explanation possible, and more likely to find the very idea of such an explanation uncomfortable. One of the largest predictors of which phenomena

When it came to romantic love, respondents were less likely to consider a scientific explanation.

were judged to fall within, versus beyond, the scope of science was whether the phenomenon was thought to be uniquely human: The more a phenomenon was thought to contribute to making us exceptional, the less possible and comfortable a scientific explanation was deemed.

If human exceptionalism explains our aversion to playing God when it comes to scientific interventions on humans, it might also explain our aversion to intervening in aspects of the natural world that make it special *for us*.

The trouble is that human exceptionalism is almost certainly false. If we are exceptional, it's in no small part because of the progress we've made in understanding the natural world and developing tools to manipulate it. One of the most important outcomes of this understanding has been recognizing our own place *within* the natural world—one organism among many, albeit one we care a lot about.

Individual cases of playing God may well be morally reprehensible, just as any act or use of technology can be. Acts of playing God could be driven by morally unacceptable motivations, expose us to morally intolerable risks, or have morally objectionable consequences. Gene-edited babies are a case in point: Proceeding without adequately considering risks and consequences is morally unacceptable. But the mere act of playing God—of trying to improve ourselves and our world—is surely among the most human.

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The Spirit of the Inquisition Lives in Science

What a 16th-century scientist can tell us about the fate of a physicist like David Bohm

BY MICHAEL BROOKS

CHRISTIANO BANTI

I'VE BEEN TALKING TO Jerome Cardano for years now. What's more, he talks back to me—in a voice that often drips with gentle mockery. He clearly thinks my sanity is as precarious as his always was.

Jerome was Europe's pre-eminent inventor, physician, astrologer, and mathematician in the 16th century. He created the first theory of probability, and discovered the square root of a negative number, something we now call the imaginary number and an essential part of our understanding of how the universe holds together. He invented the mechanical gimbal that was to make the printing press possible. His idea led to the "Cardan joint" that takes the rotary power in the driveshaft of your car's engine and allows it to be transmitted to the front and rear axles. He pioneered the experimental method of research in areas as diverse as medical cures for deafness and hernia, cryptography, and speaking with the dead (forgive him, his were not strictly scientific times).

My obsession with Jerome has taken me over. I've been schooled in quantum physics and trained to think rationally, dissecting facts and ideas dispassionately. And here I am constantly carrying on imaginary conversations with a 16th-century astrologer. Perhaps the most amusing aspect of this is that Jerome is not remotely humbled by talking to someone from the future. On the contrary, he feels he has earned such visitations through his earnest attempts to discern the truth about how the universe works.

He's not altogether wrong about this. I was first drawn to Jerome by a simple statement in his autobiography: He told his academic colleagues that many of his best ideas came from a spirit that visited him at night. He knows this is an odd claim, but he also sees himself as a pioneering visionary who would be worth the attention of celestial beings. He even writes in one of his books that, on his death, "The earth will not cover me over, but I will be snatched up to high heaven and live in distinction in the learned mouths of men." This is precisely why he is willing to take so many intellectual risks: He doesn't worry about being taken seriously on Earth when he already feels he is taken seriously in the heavens.

Whenever the powerful are threatened by progress, they will suppress debate. Science has not escaped this phenomenon.

There is a neat payoff to this hubris. Jerome's belief that a visiting spirit holds secrets that are yet to be revealed to humans means he also appreciates there is a lot that is still hidden from him. Jerome is aware that he doesn't have all the information required to understand the universe, and I find his acknowledged ignorance engaging. As an observer of science, I'm fascinated by the gaps—known and unknown—in our understanding of the universe. There are plenty of gaps in Jerome's understanding too, but he seems more aware of his evidential gaps than do many of the scientists I meet.

If only more of Jerome's contemporaries—particularly those running the Catholic Inquisition—had shown a similar humility, we might know more about him. In 1570, Jerome was arrested by the Inquisition. We don't know exactly why, because one of the many conditions of his eventual release under house arrest was that he could never discuss the reason for his initial detention. The charge could have been that he once presented the Pope with a horoscope of Christ. It might have been Jerome's pronouncement that a loving God couldn't possibly condemn devout Jews or Muslims. Or maybe it was his writings considering "whether there is one universe, or more, or an infinity of them." After all, that was among the questions that pushed the Inquisition to burn Giordano Bruno at the stake two decades later.

I've been schooled in quantum physics and trained to think rationally. So why am I carrying on imaginary conversations with a 16th-century astrologer?

Other conditions of Jerome's release included that he could no longer teach or publish—which may explain why he fell into obscurity and you are only just learning about him now. But despite Jerome's life story being relatively unfamiliar today, his experiences of what happens when people reject orthodoxy are not. The spirit of the Inquisition has never been fully extinguished; wherever the powerful are threatened by progress, they will suppress debate. Science has not escaped this phenomenon. Even something as fundamental as quantum mechanics, built on the twin pillars of probability and imaginary numbers that Jerome erected, has been stunted by censure. There are a number of examples even within this small area of physics, but perhaps none is more resonant of Jerome's experience than the story of David Bohm.

DURING THE LATTER PART of World War II, when Bohm was a graduate student at the University of California, Berkeley, J. Robert Oppenheimer recruited him into the newly formed effort to build an atomic bomb. Bohm's contributions to the Manhattan Project were so valuable that they were immediately classified and Bohm was shut out. Even though Oppenheimer was his Ph.D. supervisor, Bohm was not allowed to write his own Ph.D. thesis. He only got his Ph.D. after insisting that Oppenheimer vouch for the quality of his work.

By 1950, Bohm was working with Einstein at Princeton, where his past came back to haunt him. Early in his Ph.D. studies he had joined a trade union and, briefly, a couple of communist groups. Those communist associations, coupled with the national security implications of his Ph.D. work, made him a target for Senator Joe McCarthy's crusade against un-American activities.

Bohm refused to answer questions, and refused to name anyone that the McCarthyists should investigate. He was arrested. By the time he was acquitted, he had been suspended from Princeton. In 1951, unemployable in the United States, Bohm took a job in Brazil. The United States authorities then confiscated his passport and he was forced to apply for Brazilian citizenship. It was as a Brazilian that he traveled to England and began a long career as a professor of theoretical physics at Birkbeck College in London. There, he successfully applied for a British passport. Then, in 1986, he won back his American citizenship in a legal battle with the U.S. government.

Nothing in that long and painful saga distracted David Bohm from physics. He made significant contributions in a variety of areas, but it is for his interpretation of quantum physics that he is best known. In 1952, Bohm published a seminal paper that is now seen as a complementary, but independently derived, version of work begun decades before—and then abandoned—by the French aristocrat and physicist Louis de Broglie.

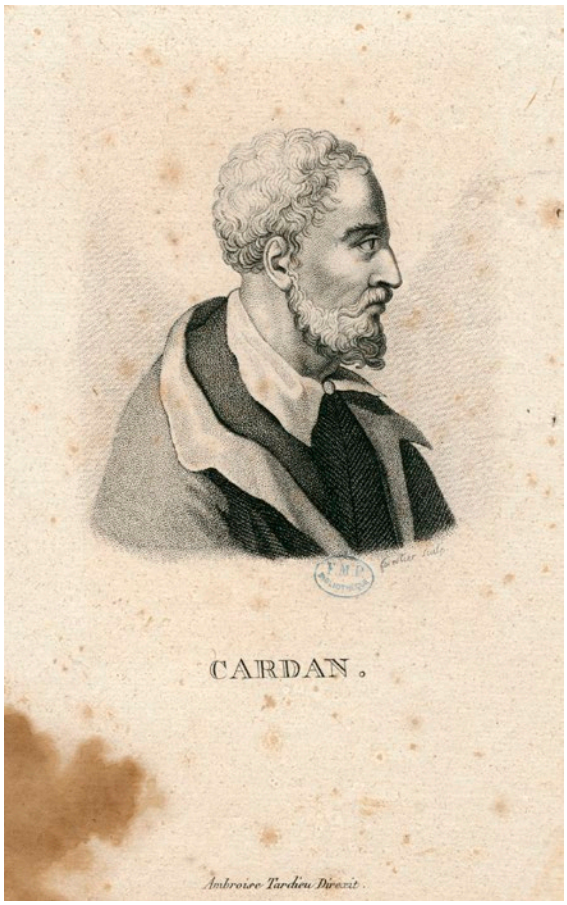
De Broglie first mentioned it in his 1924 dissertation. He brought it up again when he gave a talk in October 1927, at the same meeting where Albert Einstein and Niels Bohr had their famous debates over quantum theory. In his talk, he spoke about the *théorie de l'onde pilote*—pilot wave theory.

It deals with the "double slit experiment," where quantum objects such as photons seem to have two different locations at once before this anomaly is resolved at the photon detector. Bohr's view (now central to the "Copenhagen" interpretation of quantum theory) was that the objects have no definite position or momentum until they hit the detector. According to de Broglie, though, each photon fired at the double slit exists as a real object. He suggested it has a definite position and momentum at all times. What you can't know is the initial position.

And since the initial position would be what you combine with the momentum to give you the final position, you can't know the final position in advance, explaining the apparently random outcomes of each measurement.

Because it is a real object, with a well-defined position, the photon can pass through only one of the slits. However, its trajectory is guided by a "pilot wave," in much the same way that a ferry entering a treacherous harbor is guided by a pilot boat. This pilot wave is also real and has properties that are a reflection of the "wave function" in the theory described by the Schrödinger equation.

Because of this link to the Schrödinger equation's wave function, although the particle will only pass through one of the slits, there is still a final distribution of particles determined by an interfering wave. That means the major consequence of interference—the strange clumping at certain points on the target and absence at others—will occur.



SKEPTIC ASTROLOGER Jerome Cardano, pictured in this rendering, was convinced stars and planets exerted some influence on people. But as a rational thinker, he was conflicted. "A man is a fool who attaches too much meaning to insignificant events," he wrote.

WIKIMEDIA

Fortunately, the brainwashed generation is passing: The Copenhagen interpretation doesn't dominate like it used to.

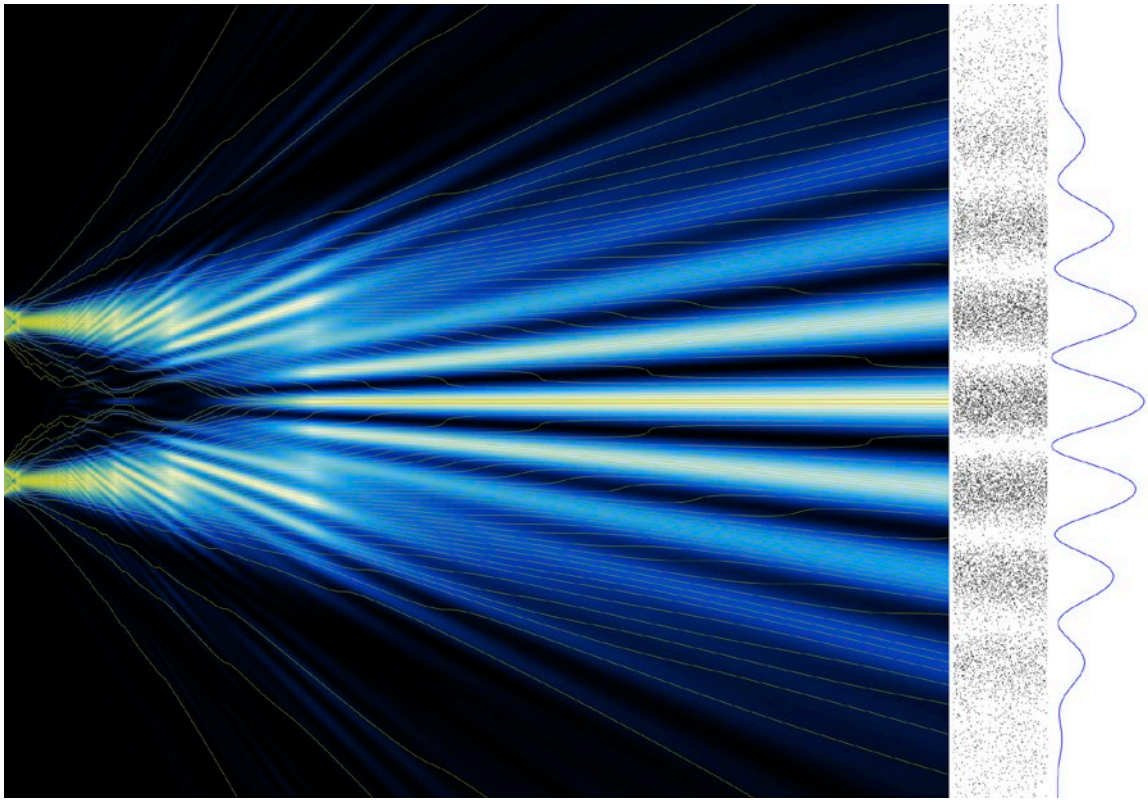
Eventually, de Broglie abandoned his idea and fell in with Bohr, becoming what we would now call a Copenhagenist. It wasn't that the pilot wave theory was particularly flawed; it was just that Bohr was probably too powerful and charismatic a figure to resist. So the pilot wave theory sank.

In 1952, however, it resurfaced in the hands of David Bohm. Bohm's idea of an invisible, undetectable pilot wave was roundly criticized, but a man who had survived the McCarthy witch hunts was not easily put off. Having overcome the most heinous character assassination of the era, he could take a little heat. And so he stuck to his guns, suggesting we needed to look at quantum experiments in a different way. In a 1952 paper published in *Physical Review*, he said, "the history of scientific research is full of examples in which it was very fruitful indeed to assume that certain objects or elements might be real, long before any procedures were known which would permit them to be observed directly." In other words, why shouldn't there be an as-yet-undiscovered pilot wave?

"Of course, we must avoid postulating a new element for each new phenomenon," Bohm continued. "But an equally serious mistake is to admit into the theory only those elements which can now be observed ... In fact, the better a theory is able to suggest the need for new kinds of observations and to predict their results correctly, the more confidence we have that this theory is likely to be good representation of the actual properties of matter and not simply an empirical system especially chosen in such a way as to correlate a group of already known facts."

So far, so good, perhaps. But there are two problems. The first is that, in order to get the predictions right about the interference effect and the ultimate distribution of the photons at the detector, you have to work backward from the final result.

The second problem is that Bohm's pilot wave is odd—in a way that physicists call "nonlocal." This means that the properties and future state of our photon are not determined solely by the conditions and actions in its immediate vicinity. The photon's pilot wave and the photon's wave function are linked to the wave function of the much, much larger system in which they sit—the wave function of the whole universe, effectively. So our photon can be



MAKING WAVES A simulated image of the double-slit experiment, in which the wave function of atomic particles pass through two slits at once. David Bohm's idea of an undetectable pilot wave was criticized, but the physicist who survived the McCarthy witch hunts was not put off.

ALEXANDRE GONDRAN

instantaneously affected by something that happens half a universe away.

Many physicists—most physicists—are not happy about allowing this nonlocal action. After all, such action is prohibited by Einstein's special theory of relativity, which says an influence can't travel faster than the speed of light.

On the plus side, it does give us an explanation for the relativity-breaking entanglement-based phenomena that Einstein derided as "spooky action at a distance." And it's not clear that accepting Bohmian mechanics is any worse than shoehorning entanglement into a relativity-friendly physics. Many fine physicists are certainly happy to talk in terms of Bohmian mechanics. I attended a conference in Vienna where an experimenter called Aephraim Steinberg explained his experimental results from a Bohm-eyed view; this, he says, is the easiest way to think about it. What Steinberg presented was a picture showing the trajectories of photons as they pass through the double slit apparatus. In the Copenhagen interpretation, remember, this is impossible because the photons have no meaningful existence before they are detected. Without an existence, they can't logically have a trajectory.

The de Broglie-Bohm interpretation of quantum physics, as it is now known, is not popular. Only one venerated physicist has ever really championed it: John Bell, the Irishman who came up with the first definitive

test for the existence of entanglement. Here's what Bell had to say:

> While the founding fathers agonized over the question 'particle' or 'wave', de Broglie in 1925 proposed the obvious answer 'particle' and 'wave.' Is it not clear from the smallness of the scintillation on the screen that we have to do with a particle? And is it not clear, from the diffraction and interference patterns, that the motion of the particle is directed by a wave? De Broglie showed in detail how the motion of a particle, passing through just one of two holes in the screen, could be influenced by waves propagating through both holes. And so influenced that the particle does not go where the waves cancel out, but is attracted to where they cooperate. This idea seems to me so natural and simple, to resolve the wave-particle dilemma in such a clear and ordinary way, that it is a great mystery to me that it was so generally ignored.

Bell felt de Broglie-Bohm was a better bet than anything the Copenhagenists had to offer. They had elevated the issue of measurement to the status where it was fundamental to the subject without ever making clear what it actually entailed. "The concept of 'measurement' becomes so fuzzy on reflection," Bell said, "that it is quite surprising to have it appearing in physical theory at the most fundamental level … does not any analysis of measurement require concepts more fundamental than measurement? And should not the fundamental theory be about these more fundamental concepts?"

Bell is widely venerated. Go to quantum physics conferences and his name comes up again and again, with some people quoting from his writings as if from scripture. He has the advantage, from the fame perspective, of having died suddenly and relatively young. A cerebral hemorrhage took him out of the blue in 1990, aged just 62. But even his influence is not enough. When it comes to quantum interpretations, the Copenhagenists appear to have won the day. For now, at least.

AS I HAVE SAID to Jerome many times as we discuss this deplorable situation, the Copenhagen interpretation can't last. It doesn't give us an answer to the question "why" when we see the results from the double-slit experiment; it refuses to explain anything about what reality looks like. Steven Weinberg has called it "clearly unsatisfactory." Murray Gell-Mann, who died in May 2019, said the Copenhagen interpretation has survived for so long only because "Niels Bohr brainwashed a whole generation of theorists." The phrase made Jerome chuckle. "That's a nice way of putting it," he said. "All doubts and questions rinsed away in a flow of appealing nonsense." He shook his head and laughed again. "I suspect my entire life has been a struggle against having my brain washed."

Fortunately, the brainwashed generation is passing: Copenhagen doesn't dominate like it used to. Just as Jerome's inventions and creations ultimately survived the strictures of the Inquisition, Bohm's ideas are also still alive, despite some of the "killer blows" they are reputed to have suffered. There are other options, too. The many-worlds interpretation, where quantum events occur in separate realities, is growing in popularity. This is more appealing to Jerome; he always liked the dangerous idea of a plurality of worlds.

In the end, we can be reasonably confident that none of our current interpretations of quantum theory are right. The most likely scenario is we, like Jerome, don't have all the information necessary to make a correct inference about the nature of reality. The point, though, is to keep trying. Why wouldn't we? As Jerome said, "There is nothing better than a mind that understands everything."

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"WHY SPORTS DIE"

ILLUSTRATION BY **VICTO NGAI**

WeChat Is Watching

Living in China with the app that knows everything about me

BY BARCLAY BRAM

IT'S 9 A.M. on a typical morning in Chengdu and I'm awakened by the sound of my phone alarm. The phone is in my study, connected to my bedroom by sliding doors. I turn off the alarm, pick up my phone, and, like millions of people in China, the first thing I do is check my WeChat. At 9:07, I send my first message of the day.

WeChat, the brainchild of Tencent—one of China's big three tech giants—is often referred to in the West as a social media app, something equivalent to Facebook or WhatsApp, but that's to undersell it. WeChat has over 1 billion active users. In China, people don't refer to it as a social media platform but rather as a social *ecosystem*. The features are seemingly endless. Beyond the typical social media functions of messaging and a Twitter-style feed called "friend circle," it can be used to make payments for almost anything. Because developers can slot their apps directly into WeChat and tie them into the social and payment functions, it acts like a very sleek and efficient operating system. If it wasn't for the fact that I grew up in London and use a VPN to jump the great firewall to keep in touch with my friends at home and use Google, I could go entire days without leaving WeChat.

At 9:27, once I've brushed my teeth, answered a few messages, and wiped the sleep from my eyes, I order a coffee through WeChat. There's a payments window on the app, and when you click on it you see various options, some proprietary to WeChat and some which are independent apps that run on WeChat's platform. I open the Meituan delivery app and scroll through all the coffee options around me. I order an Americano. I have my WeChat linked with the facial recognition scanner on my iPhone; when I pay, I just hold my phone up to my face and a green tick flicks across the screen. Seven minutes later, I get a message telling me the coffee is on the way, with the name and number of the delivery driver. It arrives at 9:53.

Before 10 a.m. on a normal day in Chengdu, WeChat knows the following things about me: It knows roughly when I wake up, it knows who has messaged me and who I message, it knows what we talk about. It knows my bank details, it knows my address and it knows my coffee preference in the morning. It knows my biometric information; it knows the very contours of my face.

But this isn't all it knows. I use WeChat to pay my rent. I use it to pay for my utilities. I use it to top up my phone credit. I use WeChat to pay for the metro system. I use it to scan QR codes on the back of shared-bike schemes throughout the city. I use it to call cabs. It knows where I go and how I go there. I follow bloggers on it, I follow media organizations and NGOs and government offices (there are over 20 million official accounts associated with governmental institutions, agencies, or officials) and I read their content through it. It knows what academic interests I have—I'm researching mental health and I pay for and attend online courses in psychology through the app. I book movie tickets, order things through Jingdong's page (the Chinese Amazon), and I recently downloaded a WeChat app which allows me to take a photo of a flower and have it tell me the name. It also tells me anytime it's been mentioned in Chinese poetry.

Then there are the features I don't use. I could get a loan through WeChat. I thankfully haven't had to book a doctor's appointment through WeChat yet, but if I did it would know what afflicts me. I'm not married but those who are can, if they must, book divorce proceedings through WeChat.

All this is to say that WeChat has metastasized into every aspect of people's lives in China. The scholar Yujie Chen, a lecturer in Digital Media and Communication at the University of Leicester, who has written a book on WeChat, calls it "super-sticky" because of the way that it has managed to make itself inextricable to so many aspects of daily life in the country. According to one estimate, WeChat alone ploughed $50 billion into the Chinese economy in 2017.[1] It is the ultimate

GYN9037 / SHUTTERSTOCK; FREEPIK

in data centralization and because of the nature of the digital economy the more data it has the more efficient it becomes—and the more easily it can pivot into new markets.

Research by Seagate and IDC group, a data intelligence firm, has recently announced that by 2025 China will hold 27.8 percent of the world's data, compared with 17.5 percent that will reside in the United States. This data will also be far more concentrated in an even smaller oligopoly of titanic tech firms, making it even more useful for the development of artificial intelligence and the next generation of big-data technologies.

WeChat knows what I am reading. It would discover I am doing research for this article.

While it is true that all the data I share with WeChat I also share with Google, Amazon, Uber, Twitter, and Instagram, WeChat is unique in that it has managed to capture all of the functionalities that these companies do separately in the West. By co-opting their Chinese equivalents into its social ecosystem, it swallows all of the data they generate.

As debates rage in the West about the extent to which we are comfortable with tech monopolies and what happens with our data, WeChat provides a window into a world of almost total data-centralization.

THE WORD 隐私 *yinsi*, which is often how privacy is translated, is an imperfect match for the English term and reads more as something that is secretive or needing to be hidden. Something that is private in English is inherently neutral, as it is assumed in our individualistic society that there should be spaces beyond the reach of governments, corporations, or others. In China, where society is more collective, family units are less atomized, and there's a long history of the government being minutely involved in all aspects of a person's life, the private realm is far less demarcated.

The irony of WeChat is that part of its initial success as a platform was predicated on the idea that the user interface provided more privacy than that of its rival Weibo. While Weibo functions much more like Twitter—posts can be viewed by anyone and users have visible follower counts and their public influence is more easily gauged—WeChat initially functioned more as a private messenger along the lines of WhatsApp. Later features like friend circle, which allow posts to be viewed by all of a person's followers, were more private in the sense that only once your friend request had been accepted could you view that person's posts. You can't view the number of likes under a post; you can only see if mutual friends have liked them. You can also create groups on WeChat and broadcast within them to people outside of your friend circle, but they are capped at 500 people.

In 2013, after Xi Jinping emerged as China's leader and started to draw tightly on the reins of power, one of his early moves was to invite a number of "big V" account holders[2] (verified Weibo accounts of celebrities

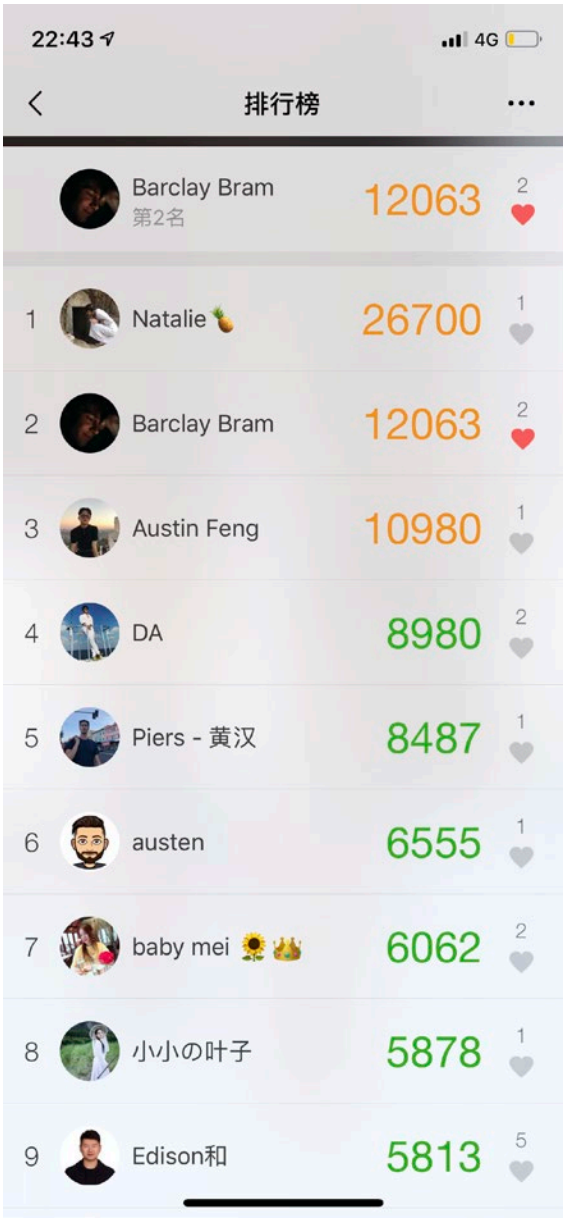
and popular bloggers with thousands or millions of followers) for "tea"—a euphemism for a stern talking to from the central government—and to publish new guidelines which said a post viewed over 5,000 times that offended government sensibilities such as "damaging the national image" and "causing adverse international effects" would lead to three years in prison.[3] There was a swift exodus from Weibo toward WeChat as the latter was deemed politically safer because of its more closed and intimate design.

This design feature, which came out of the demands of a heavily censored Internet environment, is ironically finding its adherents in the Internet free-for-all of the West. Facebook's recent announcement to push for a more private user-experience led many commenters to note that the reformed Facebook sounded a lot like WeChat.[4]

Despite WeChat's somewhat more private design, Amnesty International, in a 2016 report on user privacy, gave WeChat zero out of a 100 for its lack of freedom of speech protection and lack of end-to-end encryption. By comparison, Facebook scored 73. People are regularly arrested for messages they send in supposedly "private" group chats. In 2017, two people were arrested in Nanjing for separate instances of making satirical comments referring the massacre in the city by the Japanese in 1937.[5] One person, seeking a job in the city and down on his luck, wrote in a group for job-seekers that "Nanjing is a pit. We should let the Japanese come slaughter again." He was detained two days later. A similar case that same year saw a 31-year-old man jailed for joking about joining the Islamic State in a group-chat. He was arrested under China's anti-terrorism laws and given a nine-month prison sentence.[6]

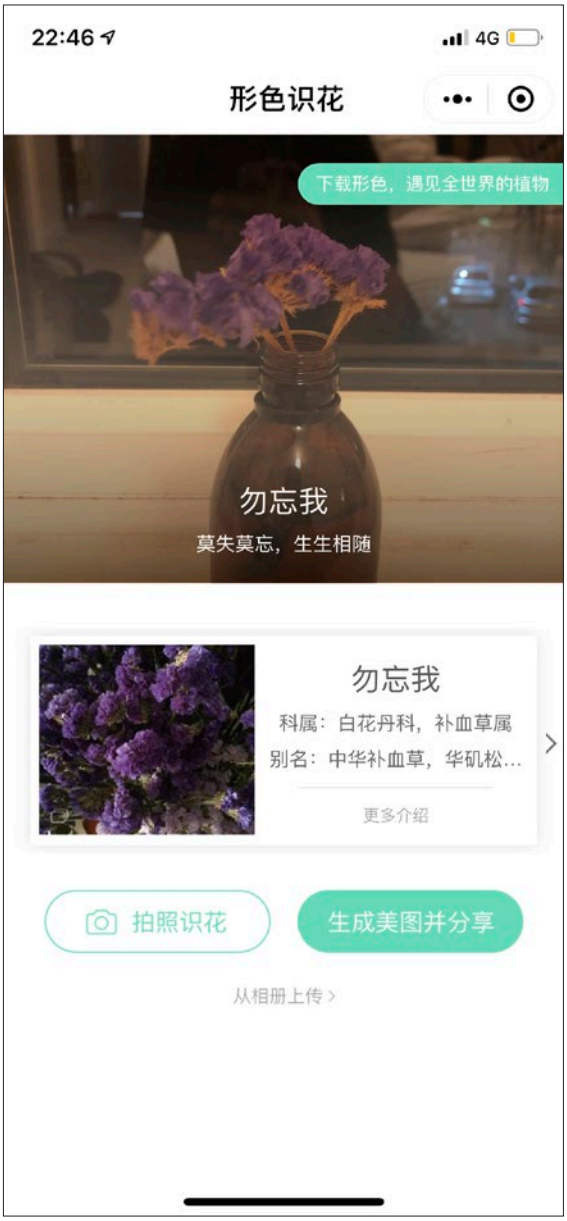
In 2017, regulations were passed that said the "owners" of WeChat groups are legally responsible for content posted by other members, and that complete chat logs should also be stored for potential police use for a period of at least six months.

Despite its user interface being more private in a general sense than Weibo, the fact that it is censored is widely known and has been a point of contention in its wider plans for global expansion. The Citizen Lab, an interdisciplinary lab at the Munk School of Global Affairs and Public Policy, at the University of Toronto, reports that WeChat's censorship is stronger



WE RUN A screenshot from the author's WeChat app compares how many steps he's taken in a day, ranked against his friends—a reminder that even with a daily action like walking, the omniscient app has got his number.

SCREENSHOT COURTESY OF THE AUTHOR



FLOWER POWER A screenshot of a WeChat app that identifies flowers and informs users when that flower is mentioned in Chinese poetry. Everything on WeChat is part of China's social ecosystem.

for people who are registered with a domestic phone number.[7] Messages and photos that won't show up for a person who registered in China might show up for a foreigner. Today, you don't know when a message has been censored. In earlier versions of WeChat, a message would show up and tell you that your message had been blocked for containing keywords that violated certain laws and regulations of the PRC (People's Republic of China). Today, messages just don't appear at all. You'll only know if you compare your chat log with that of the sender.

Despite this reality, there is a nascent privacy awakening in China. A number of domestic scholars wrote that 2018 was a landmark year in both awareness of privacy and the construction of a legal regime to protect personal data.[8] But this conversation isn't about privacy from the government—that is a moot point in the context of China. Rather, the privacy debate is about what happens to your data. As Yujie Chen notes, part of the driver behind the privacy awakening in China is a global trend in which people "now understand the business model of the Internet companies—that is, selling individual's data."

In China, where there has until only recently been little in the way of legal protection over personal data, it is common for granular private information to be sold by tech companies to third parties who use them for targeted advertising. The artist Deng Yufeng exposed this reality in his solo show at the Wuhan Art Museum in 2018, where he displayed the private details of over 300,000 people—their addresses, names, bank numbers, and phone numbers—that he had bought online from data they had shared willingly to a tech company which had sold it on without their permission. "Do we have any secrets anymore?" a neon-panel asked in the final room of the show.

Combating this trend has led the Chinese government to issue comprehensive data privacy rules. In May 2018, the government issued a "Personal information security specification,"[9] a standard for enhanced privacy, and an auditor affiliated with the Ministry of Industry and Information Technology published a list of 14 mobile apps that had "excessively collected sensitive personal data" without user consent.

The new data rules, however, underscore how privacy in China is not the same as in the West. Advocates

SCREENSHOT COURTESY OF THE AUTHOR

People are regularly arrested for messages they send in "private" group chats.

here warn that an individual's rights to privacy, free speech, and a free press—the principles of democracy—are undermined by government surveillance. In China, privacy rules are designed to curtail private companies from collecting and profiting from data. The Chinese government retains the right to use it for political purposes, such as quelling public protests before they happen. Still, to the extent that the Chinese government is increasing privacy protections on my data on WeChat, the user experience is little changed. Nothing has changed with how I use the app or how much data I willingly hand over to it.

AT 10:44 A.M. IN CHENGDU, I get a text from *yidong*, the mobile service provider I use, to say I am out of credit. When I see the text at 11:04, I pay my phone bill immediately through the payments page on WeChat. At 11:15, I walk to a yoga class. I had asked the teacher, via WeChat message, a few days before if the class was still happening because of spring festival. I check in at the gym with WeChat and then for two hours WeChat doesn't know exactly what I am doing since I put my phone in my locker—but it would be able to make a fairly good guess. As I leave the gym I get a coffee at 1:30 p.m. and open some articles my friend has sent. They open within WeChat—there are no external links within the WeChat universe—so WeChat knows what I am reading. It would discover I am doing research for this article. I am reading about WeChat.

The data that WeChat creates is a boon for the government. On an aggregate level, WeChat provides "heat-maps" that can show the government in real-time how many people are using the service based on location data, which allows them to predict and outrun mounting protests or build-ups of people. On a granular level, the government has exemptions from data-protection laws which anonymize data and which, supposedly, prevent companies from singling out specific individuals from their wider data pool.[10] WeChat's encryption doesn't prevent the government from being able to use the data as it sees fit. Legally, WeChat's terms and conditions allow for user data to be retained "as long as is necessary" to "comply with laws and regulations." Tencent doesn't disclose when the government requests user data and gives no detail of the kind of encryption, if any, it employs.

At around 4 p.m., I have a problem with a money transfer. So I call the bank branch where I opened the account in the northeastern city of Dalian, a full four hours away by flight. The bank teller tells me that I was getting money from an institution (a scholarship from my university in the United Kingdom), so I need to prove my student credentials before they process the transfer. She adds me on WeChat, using the phone number I'd called into the bank, and I send her all the relevant documents. She processes the transfer and sends me screenshots of her authorizing the money to be sent into my account.

Hyper-centralization makes life convenient. It also presents a worrying potential for fraud. On a typical day I've paid my phone bill, sent money to people, bought groceries, and even sent authorized documents to the bank, all through one app, protected by one password and kept intentionally unencrypted to comply with government data-sharing regulations.

It is extremely difficult to gauge the number of accounts that get hacked on WeChat per year (Tencent declined to comment for this article). But the scope of the problem of online fraud in China is widespread. In a survey held by Internet Society of China, an NGO made up of 1,200 members, including key Internet leaders in the country, 84 percent of respondents said they had suffered some sort of data theft. In 2016, the death of Xu Yuyu, an 18-year-old girl whose family was defrauded of the savings they'd accumulated for her to go to university, sparked a debate about data privacy.[11] A court ruled her death, by heart attack, had been the direct result of the fraud. A man was sentenced to life in prison for paying a hacker to steal her private details.

PHONE HOME WeChat's launch page gives the impression you can chat with anyone, anywhere, as it looms watchfully over your shoulder, like the moon.

SCREENSHOT COURTESY OF THE AUTHOR

Today we are our own informants, writing the most detailed personal accounts ever collated.

Moreover, the data centralization that has enabled WeChat to map itself neatly onto users' personal and commercial lives, has now created an opportunity for the government to step in and invite it into their political lives. Beyond sharing data with the government, WeChat is now rolling out a digital ID card. Every Chinese citizen is issued an ID card. It functions like a domestic passport and is needed for any interaction with the state—at hospitals, booking trains, flying domestically, or making bank transactions. In Guangzhou, the provincial government has already debuted a WeChat ID card and there are plans for it to be rolled out across the whole of China. Hijiacking WeChat in the future could grant a hacker everything from a user's government-approved identity to his or her bank details, address, and coffee preferences.

WeChat's data centralization makes it a cornerstone of the government's social-credit system that is feted to appear nationwide in 2020. Mooted in 2014 in a document entitled "Planning Outline for the Construction of a Social Credit System," the plan is to build a system that incentivizes good behavior and punishes that deemed unconducive to the construction of a harmonious society or, as the document itself dictates, a system that will "allow the trustworthy to roam everywhere under heaven while making it hard for the discredited to take a single step."[12] Under the pilot scheme, people with outstanding court orders or who have defaulted on loans can't book high-speed rail tickets and can't fly in planes.

The nationwide social credit system will be compiled by combining government records with commercial profiles. At present, Ant Financial, the finance-arm of Alibaba, China's Internet conglomerate, has rolled out "sesame credit," which gives people a score out of 950 based on their punctuality paying back loans, their purchase history, their social networks (having friends with high scores boosts your own score), and data shared from the government such as court-orders and fines. People with high-scores get preferential loans, can rent cars without deposits and are even guaranteed visas for countries like Luxemburg and Singapore, among other perks. China Rapid Finance, which is partnered with Tencent, is responsible for creating a similar scheme off the back of WeChat data.

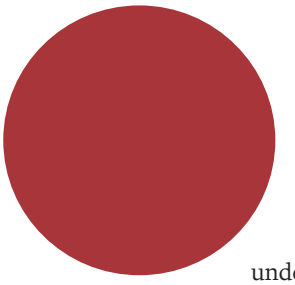
So, what does this mean for me? It isn't clear yet how the social credit system will play out for foreigners in China. My sesame-credit score is a paltry 570 and China Rapid Finance hasn't made its social scores available to view yet. There is, however, already a feature on WeChat that has been rolled out in Hebei province. It shows you the deadbeats in your vicinity—a literal map, dotted with clickable icons of anyone within 500 meters of you who has failed to pay back a loan recently.[13] It also shows their national ID numbers and explains why they're being named and shamed.

I often hear people repeat the refrain, both here in China and in the West, that they have nothing to hide, so they have nothing to fear from the data that they've handed over. In the West, where we have a neo-liberally informed suspicion of government, we've gladly handed over our data to corporations, believing them to be benign. Amazon already has a system that installs a digital key on people's homes that their delivery drivers can open to ensure safer deliveries.[14] People then buy an Amazon cloud cam to watch the delivery in real time.

It is only in the wake of scandals such as Cambridge Analytica and the Russian leveraging of social media to influence the 2016 election that we have started to question whether this trust might have been misplaced. In China, where people have a different relationship to privacy and a tacit understanding that the government was always going to take hold of this data once it became available, voices in dissent are muted.

The problem is WeChat is vulnerable. I don't know what I'd do if my account was hacked today; and this is without WeChat being my government issued ID and prior to it influencing my social credit score. I may have nothing to hide, but that presupposes two conditions; one, that I understand where society stands on a particular behavior or thought and that I am on the right side of it (and that the line won't move once I've chosen where to stand), and secondly that I know what I am supposedly hiding.

WeChat has read every single message I have ever sent and hasn't understood a single word. Who knows what the algorithms flag in my daily life; how it chooses to interpret my interactions and to what end? I've said that WeChat knows what I read and where I took a cab to last night, but that isn't quite accurate. It has data about all of this, but *knowledge* implies understanding and interpretation—and that will be done by someone else, with their own ulterior motives. Perhaps you have nothing to hide from WeChat, but you might from whoever ends up with your data.



The author Timothy Garton Ash was a correspondent in East Germany during the time of the Stasi secret police. After the fall of the Berlin wall, he wrote a moving account, *The File: A Personal History*, of rereading the information the Stasi collected on him. "Like the materials used in a collage, these pieces of evidence have very different textures: here a fragment of hard metal, there a scrap of folded newspaper, there again a wisp of cotton-wool," he wrote, marvelling at the details he himself had forgotten of his life in East Germany but that seemed so relevant to the security forces and their web of informants. He concluded that what the files ultimately presented were "a vast anthology of human weakness," predicated on turning approximately 1 out of every 100 members of the overall population into informants.

Today we are our own informants. We have written our own digital files and diligently update them with the most frighteningly detailed accounts ever collated in human history. We have created an infinite anthology, but of what?

A few weeks ago, a friend showed me a feature on WeChat that I hadn't realized existed. WeRun links up your account with the activity monitor on your iPhone and measures your steps. At the end of every day,

WeChat broadcasts the number of steps I've walked and ranks me against my friends. Since friending a herder I met on a hike in the Tibetan foothills I've given up ever coming in first place. On that day in February I ranked 30th overall among my friends, even though I'd decided to walk to and from a restaurant with a friend to boost my score.

In total I had walked 10,771 steps. WeChat had been with me every step of the way.

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Yes, Determinists, There Is Free Will

You make choices even if your atoms don't

BY GEORGE MUSSER

J.CHIZHE / SHUTTERSTOCK

IT'S NOT JUST IN POLITICS where otherwise smart people consistently talk past one another. People debating whether humans have free will also have this tendency. Neuroscientist and free-will skeptic Sam Harris has dueled philosopher and free-will defender Daniel Dennett for years and once invited him onto his podcast with the express purpose of finally having a meeting of minds. Whoosh! They flew right past each other yet again.

Christian List, a philosopher at the London School of Economics who specializes in how humans make decisions, has a new book, *Why Free Will Is Real*, that tries to bridge the gap. List is one of a youngish generation of thinkers, such as cosmologist Sean Carroll and philosopher Jenann Ismael, who dissolve the old dichotomies on free will and think that a nuanced reading of physics poses no contradiction for it.

List accepts the skeptics' definition of free will as a genuine openness to our decisions, and he agrees this seems to be at odds with the clockwork universe of fundamental physics and neurobiology. But he argues that fundamental physics and neurobiology are only part of the story of human behavior. You may be a big bunch of atoms governed by the mechanical laws, but you are not just any bunch of atoms. You are an intricately structured bunch of atoms, and your behavior depends not just on the laws that govern the individual atoms but on the way those atoms are assembled. At a higher level of description, your decisions can be truly open. When you walk into a store and choose between Android and Apple, the outcome is not preordained. It really is on you.

Skeptics miss this point, List argues, because they rely on loose intuitions about causation. They look for the causes of our actions in the basic laws of physics, yet the concept of cause does not even exist at that level, according to the broader theory of causation developed by computer scientist Judea Pearl and others. Causation is a higher-level concept. This theory is fully compatible with the view that humans and other agents are causal forces in the world. List's book may not settle the debate—what could, after thousands of years?—but it will at least force skeptics to get more sophisticated in their own reasoning.

These questions are not abstract. They underlie the justice system and our day-in, day-out judgments about praise and blame. It is hard to think about human beings without assuming we are not the author of our own decisions. But the practical need for assuming free will is not an argument in itself.

Earlier this month, List spoke with me from his office in London, and I soon found myself wishing I could take one of his philosophy classes. He laid out the issues step by step and stayed clear of the jargon and rabbit holes into which many philosophers fall.

What really struck me about the book is you give a fair presentation of the case you're going to argue against. I wish more academics did that. So what is the argument against free will?

A free-will skeptic argues, first, that free will requires one or more properties: intentional, goal-directed agency; alternative possibilities—that it must be possible for me to do otherwise; or causal control over our actions. Then the skeptic claims that those properties are not to be found among the fundamental physical features of our world. Different skeptics focus on different properties.

For instance, some neuroscientists and philosophers such as Patricia and Paul Churchland say we should understand human behavior not so much at the cognitive, psychological level where we invoke explicit mental states, goals, intentions, and purposes, but rather at a lower level of description, as the product of biophysical processes in the brain. Human beings have a strong tendency to ascribe intentions to all sorts of phenomena, like the weather, natural disasters, or rivers. We no longer do that. As brain science becomes more advanced, we may dispose with ascriptions of intentionality even to human beings.

The second line of argument says, if the universe is deterministic, as at least some of our best physical theories suggest, then there is no room for alternative possibilities to choose from. Determinism is the thesis that if we fix the complete state of the universe at a particular point in time, only one future trajectory of states is possible. If we fix the state of the world at the time of the Big Bang or shortly after, the entire sequence of events thereafter would be inexorably fixed. When you go to a café and you ask yourself, "Should I have a coffee or a tea?" it would be already written into the initial state of the world which of those two choices you're going to make.

The third line of argument is that, when I raise a water glass in order to drink from it, it's not really my intentional mental state that causes this action. Rather, it's some underlying, subconscious, sub-intentional physical process in the brain. Benjamin Libet found that the conscious decision to press a button is not the beginning of the causal sequence that initiates the process, but there is first a certain pattern of unconscious or subconscious brain activity, and he interpreted this as a challenge for free will.

BOOK OF DANIEL "When I read Daniel Dennett's books, I found them very persuasive," says Christian List (above). "I began to see little gaps or instances of imprecision. I decided a more thorough and systematic defense of free will against some of the skeptical challenges is needed."

PHOTO COURTESY OF HARVARD UNIVERSITY PRESS

There is no conceptual reason why sophisticated AI systems could not qualify as bearers of free will.

These arguments have considerable force. One way to respond would be to water down the notion of free will so that one or several of the properties I've mentioned are not required. For instance, maybe it's good enough for free will that I endorse my action and it's not necessary that I could have done otherwise. Or maybe we must redefine what we mean by alternative possibilities. It might be that I was always going to choose coffee rather than tea, but if hypothetically the world had been a little bit different, I would have made a different choice.

But that's not a strategy that I find attractive. I am quite happy to concede that free will requires intentional agency, alternative possibilities among which we can choose, and causation of our actions by our mental states. I think the mistake in the standard arguments against free will lies in a failure to distinguish between different levels of description. If we are searching for free will at the fundamental physical level, we are simply searching in the wrong place.

Let's go through these arguments one by one. What do you say to those who consider the idea that humans are beings with goals and intentions, and that we act on them, a prescientific holdover?

If you try to make sense of human behavior, not just in ordinary life but also in the sciences, then the ascription of intentionality is indispensable. It's infeasible and not illuminating to explain human behavior at the level of astronomically complex neural firing patterns that take place in the brain.

Suppose I ask a taxi driver to take me to Paddington Station. Twenty-five minutes later, I'm there. The next day, I tell the driver to take me to St. Pancras Station. Now the driver takes me to St. Pancras. If I look at the underlying microphysical activity, it would be very difficult to pinpoint what those two events have in common. If we switch to the intentional mode of explanation, we can very easily explain why the taxi driver takes me to Paddington on the first day, and what the difference is on the second day that leads the

driver to take me to St. Pancras Station. The taxi driver understands our communication, forms the intention to take me to a particular station, and is clearly incentivized to do so because this is the way for the driver to earn a living.

The neuroscientific skeptic is absolutely right that, at the fundamental physical level, there is no such thing as intentional goal-directed agency. The mistake is to claim that there is no such thing at all. Intentional agency is an emergent higher-level property, but it is no less real for that. Whenever our best scientific explanations of a particular phenomenon commit us to postulating certain entities or properties, then it is very good scientific practice to treat those postulated entities or properties as genuinely real. We observe patterns and regularities in our social and human environment, and the best way to make sense of those patterns and regularities is by assigning intentional agency to the people involved.

What about the second argument, the challenge from determinism—that, before I walk into a café, it is preordained what I will order?

The jury is out on whether the world is fundamentally deterministic—it depends on how we interpret quantum mechanics—but suppose it is. This does not necessitate that the world is also deterministic at some higher level of description. Indeterminism at the level of psychology is required for free will and alternative possibilities. That is entirely compatible with determinism at the fundamental physical level.

Think about weather forecasting. Meteorologists are interested in higher-level patterns and regularities. In fact, the very notion of weather is a higher-level notion. At the level of individual air molecules, there is no such thing as weather. Perhaps the system at that very fine-grained level of description would indeed behave deterministically according to classical physical laws, but as you move to a more macroscopic description, you abstract away from this microphysical detail. That is not driven by ignorance on our part, but by the explanatory need to focus on the most salient regularities.

When you consider the macroscopic weather states, the system is not deterministic, but stochastic, or random. We can attach probabilities to different scenarios, but it's not the case that the weather state at

It's infeasible to explain human behavior at the level of complex neural firing patterns in the brain.

the present time fully determines the weather state in a few days' time. Multiple different trajectories are entirely possible.

Likewise, to describe the complete state of a human agent, we do not describe the full microphysical state of every elementary particle in the brain and body. That would be the wrong level of description. If our best theories of human agency compel us to postulate forks in the road between which agents can choose, then we've got very good scientific reasons to take alternative possibilities at face value. If you ask psychologists, cognitive scientists, and economists, they will give you different theories of how human choice-making works. But they all treat human beings as agents who are faced with choices between different options, so all these theories assume alternative possibilities.

If we are searching for free will at the fundamental physical level, we are simply searching in the wrong place.

Wait, I'm not sure I want indeterminism at the human level. I want my decisions to flow out of my deliberations, not to be the product of chance.

This is subtle. There are different forms of indeterminism. In statistical physics, indeterminism is associated with randomness. But in the social sciences, we use a different kind of indeterminism based on option availability. In decision theory, we draw a distinction between the options an agent could choose and the option the agent will in fact choose, based on maximizing expected utility or some other criteria. If I'm rational, I'm going to try to systematically make choices that are in line with my beliefs and preferences and goals. But the other options don't disappear. They are available to me right up to the moment of my choice.

A common theme I'm sensing in your arguments is that we should take the lessons of our scientific theories seriously—all our theories. If physics says the microscopic world is deterministic, we should accept that, at least provisionally until some better theory comes along. If psychology says humans have genuine choices, we should accept that, too.

Yes. It would not be very principled to say that fundamental physics is deterministic based on what our best theories of fundamental physics say, while rejecting that weather systems, for example, are indeterministic based on what our best theories of meteorology say.

Provided our best theories in higher-level sciences are well confirmed, we have good scientific reasons to take them just as seriously as we're taking our fundamental physical theories.

Let's move on to argument number three, that we have causal control over our own acts.

If we accept my response to the first challenge that we human beings are intentional, goal-directed agents, we might still worry that our goals don't play a causal role. We need to define what we mean by causation. Neuroskeptical arguments against free will invoke causal notions, but often they don't spell out precisely what they mean.

In the sciences, we test for causation by looking for systematic correlations that remain in place even when we control for other factors. The way in which causal modelers now tend to think about causation—in fields such as statistics, computer science, probability theory, and the philosophy of mind—captures this aspect of scientific methodology. This approach is called the interventionist theory of causation. To say one particular variable causes another is to say that, if we were to intervene on the first variable by changing its value, we would bring about a change in the other variable.

Let's say I now form the intention to move my arm to lift this glass to drink some water. What should we cite as the cause of this particular arm movement? My intentional mental state—namely, my intention to drink—is very systematically associated with my actions. If my mental state changes, my resulting actions change as well. By contrast, not every change or variation in the underlying physical states would give rise to a change in the resulting act.

A leading philosopher whose work I hugely admire, Jaegwon Kim, raised an important challenge against mental causation, the so-called causal exclusion argument. If you consider a particular effect and you've found a cause that fully accounts for that effect, you should not simultaneously postulate yet another distinct cause for the same effect. That would be an act of causal overattribution. Let's suppose, once again, I lift my arm to drink some water. You can fully account for the action by reference to the physical state of my brain, so there is no reason to postulate yet another cause—namely, a distinct mental cause.

My response, which Peter Menzies and I developed, is that if we accept the interventionist theory of causation, the causal exclusion argument does not generally hold. For any given system, the most systematic causal relations may not involve the lowest-level variables, but could involve higher-level variables, or there might be systematic causal relations at both levels.

Let me see whether I follow, using the taxi metaphor. You have two switches. One is a simple binary Paddington-St. Pancras switch. The other is an analog dial, and you have to fine-tune it to set the destination. It might be set to Paddington, but a slight nudge changes it to St. Pancras, and another nudge changes it back to Paddington—it's very sensitive. The binary switch is a more effective means of controlling the outcome. It is analogous to seeking a mental cause rather than an atomic one.

That's spot-on.

What do your views on free will imply? Do machines or even corporations have free will?

In my joint work with Philip Petit, I've argued that organized collectives can be intentional agents in their own right, over and above their individual members. Commercial corporations would be examples, if suitably organized. Those group agents don't have the same cognitive capacities that you and I have, but nonetheless we might say that they have a certain form of free will.

Something similar can be said about AI systems as well. One can have long debates about whether current AI systems are sufficiently advanced, but there is no conceptual reason why sophisticated AI systems could not qualify as bearers of free will. Much like corporate agents, which we also think should be held responsible for their actions, AI systems ideally should display a certain form of moral agency and not just rigid goal-seeking behavior in the interest of profit or whatever else their objective function might be. As we employ more and more AI systems in high-stakes settings, we would like those systems to make ethically acceptable decisions.

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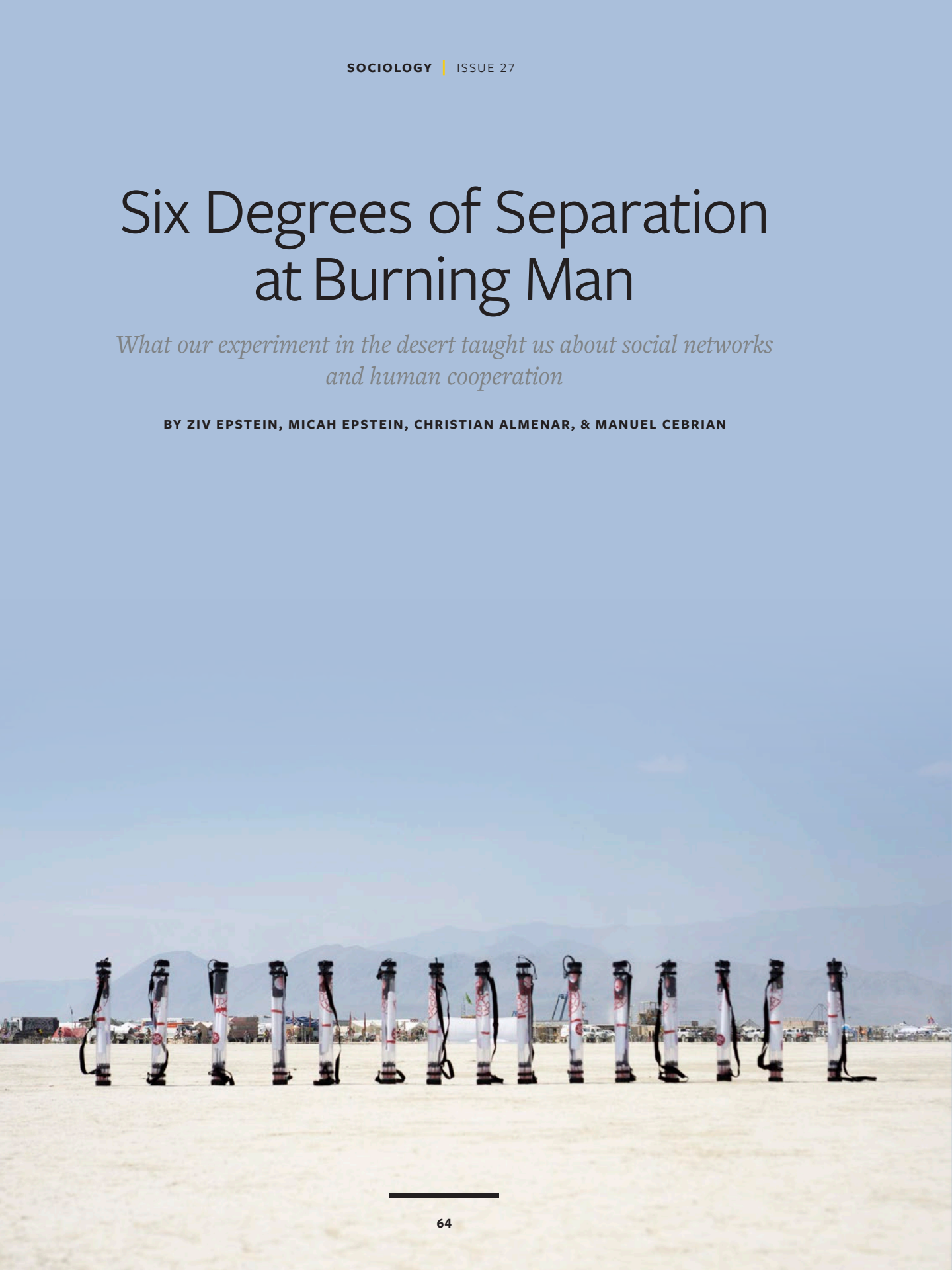
Six Degrees of Separation at Burning Man

What our experiment in the desert taught us about social networks and human cooperation

BY ZIV EPSTEIN, MICAH EPSTEIN, CHRISTIAN ALMENAR, & MANUEL CEBRIAN



TODAY THE ALKALINE DESERT is quiet. The roar of techno music and flamethrowers has been replaced with the soft clink of rakes and trash cans. Thousands of people put aside their hangovers to methodically clean the desert. After a dedicated communal cleaning, Burning Man, one of the largest arts events in the world, spanning seven days and involving over 70,000 participants, leaves not a single wrapper on the desert. Among the swarm of salt-crusted denizens of this ephemeral city (known as Burners) is us: a scientist who studies cooperation, an industrial designer, and a Silicon Valley security CEO. Among the dismantled rigs, lifeless pyrotechnics, and bowed heads of Burners absorbed in cleaning, we are here trying to answer a simple question: How, after so many years, could Burning Man throw an event of such chaos, and yet leave the desert without a trace? What leads thousands of people in such an extreme environment to consistently engage in cooperative behavior at a scale seldom seen in society?

To answer that question, we must start our journey at the MIT Media Lab, in an aptly named research group: Scalable Cooperation. This group studies how technologies—social media, the Internet, artificial intelligence—can empower cooperative human networks. The group's heritage includes the scientists who solved DARPA's Red Balloon Challenge in 2008, in which the United States government scattered 10 red weather balloons across the continental U.S., and instructed teams of researchers to locate them as fast as possible. The winning MIT team found all 10 balloons in just under nine hours using the virality of social media and an incentive structure that motivated people to recruit their friends. This result was a resounding success for crowdsourcing and the Internet at large, demonstrating that a collective of individuals, connected through technology, could together solve large-scale problems that no individual could solve alone.

This same team, however, struggled with other Internet-based forms for mass cooperation. During the 2011 DARPA Shredder Challenge, which involved recruiting and coordinating individuals on the Internet to collectively recombine shredded documents, people took advantage of the trust necessary for large-scale collaboration. Adversarial participants from the other teams, who felt the crowdsourcing essentially amounted to "cheating," posed as volunteers and sabotaged the crowdsourcing effort,[1] rendering cooperation impossible. Fast-forward five years, to the 2016 presidential election, and we see how this antagonism can be a serious problem for genuine collective action. Bad actors proliferated misinformation at such a rate that

THE PENDANT Ziv Epstein gifting a pendant to a passerby. These pendants contained a link so individuals could follow up on the results of the project.

BOTH PHOTOS: MICAH EPSTEIN

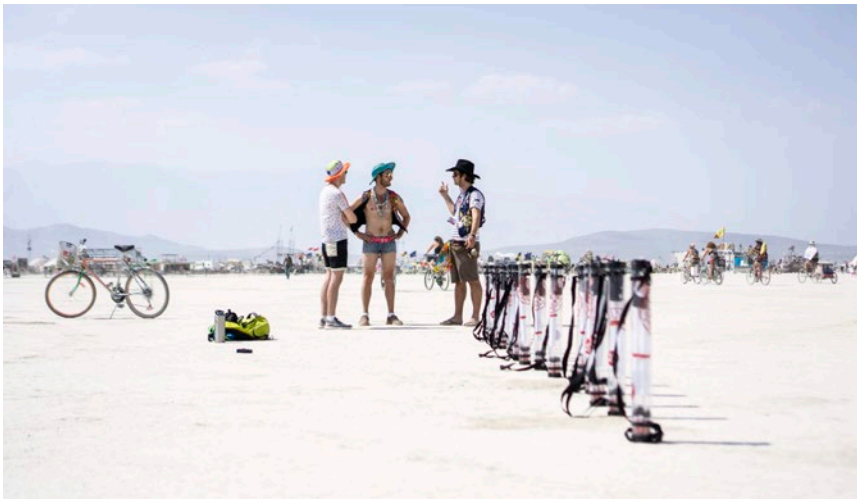
Our experiment was a play on the famous Small World Experiment, which led to the phrase, "six degrees of separation."

The New York Times declared, "The Internet trolls have won. Sorry, there's not much you can do."

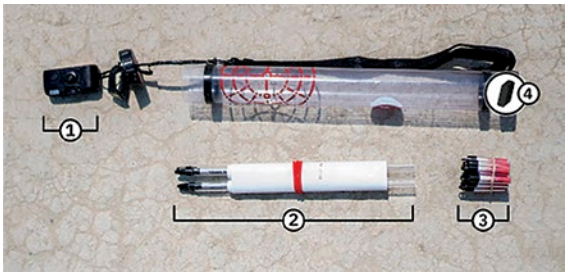
So when do networks enable cooperation to thrive? And when do they hinder it? A vast body of work from across anthropology, psychology, and sociology has explored the conditions under which cooperation—the propensity for individuals to pay a personal cost for the benefit of the whole—operates. Michael Tomasello's book *Why We Cooperate* recounts numerous experiments with children and apes to argue that cooperation is an innate trait that has evolved on an evolutionary timescale. While he acknowledges that genetics impacts cooperation, he also stresses that the environments in which we grow up fundamentally shape our ability to cooperate. Nature and nurture. A defining characteristic of our species is that we often operate within complex social institutions that both require and facilitate cooperative behavior.

Over the years, scientists have examined how these social networks can be configured to maximize cooperation. In a 2011 study, David Rand, Samuel Arbesman, and Nicholas Christakis show that many types of social networks cause cooperation to devolve.[2] In particular, they show that networks where people cannot update their connections based on interactions, or when these updates are random, cooperation decays over time. But they also demonstrate that in networks where individuals can easily change who they interact with, cooperation is stable. This suggests that how we design our social networks—our communities and our institutions—plays a critical role in determining the prevalence of cooperation.

But can we see the same effects on cooperation on the networks of society outside of the laboratory? Perhaps the most influential study that explores this question is Stanley Milgram's Small World Experiment, which sent hundreds of envelopes on journeys across the United States. Milgram was fascinated by the paths that information takes through a community and what they can tell us about the structure of social networks.[3] Milgram sent letters to random individuals in the U.S.—each containing information about a final target person, and instructions to pass the letter along to the friend who would get it closer to the target. Through this, he measured the path length between individuals and demonstrated that we live in a "small world,"



THE PARTICIPANT Christian Almenar and Ziv Epstein talking to a prospective participant on the Playa.



THE VESSEL The schematic for the Vessel. Each one contained 1) a disposable camera, 2) a scroll containing the instructions, 3) 15 pendants that contained information about the project, and 4) a GPS tracker that logged the movement of the Vessel.

BOTH PHOTOS: MICAH EPSTEIN

where a surprisingly small number of friends connect any two people (commonly known as six degrees of separation). But there was one significant flaw in Milgram's and similar experiments: Only 19 percent of the letters yielded successful chains. In digital replications of his experiment, that number dropped to as low as 1.5 percent. In all these experiments, getting people to participate was difficult. Because people are busy and engaged in their usual environments, they had little incentive to help out.

NOW LET'S RETURN to our team in the desert. To explore how and when cooperation can thrive in society, we decided to examine a different, extreme environment known for its ability to foster cooperation at a large scale: Burning Man. A community event that takes place once a year in the Black Rock Desert of Nevada, Burning Man has been characterized by some as little more than a hedonistic playground for dusty hippies and Silicon Valley's elite. Indeed, Burning Man embodies anarchy. But embedded in its chaos exists a sophisticated machinery for community organization, local governance, and participatory action. A central part of this organization is the Burning Man 10 Principles, which serve as the ideological blueprint for the entire event. The 10 Principles contain ideas such as gifting—which encourages people to share with others without any explicit compensation—and participation—which invites any person to contribute to collective action. We hypothesized that these principles create an environment where cooperation emerges in ways unseen in the world of Milgram and laboratory studies.

Our experiment, incubated in Scalable Cooperation in collaboration with computer and network scientists, was a play on the Small World Experiment. We designed it with the same structure of Milgram's original 1962 study, routing information through Burning Man's social network with a series of parcels. These

Serendipity struck once again in Rhode Island. "Wait, I think I'm part of this project!" a woman told us.

parcels, which we named "Vessels" (because everything at Burning Man can and should have a vaguely ritualistic name), were handed out on the first day of Burning Man 2018, containing information about a particular individual at Burning Man. The clearly stated goal of the vessel was to end up in the possession of this individual, so we refer to them as the Terminus. From hand-off to hand-off, these Vessels would collect a variety of information, stories, and data about their journey. We hoped these journeys would allow us to quantitatively map the connectivity of the Burning Man community and qualitatively understand how people engage with Burning Man culture. We hoped not only to count the number of hops of each successful chain, and compare that measure of social connectivity with Milgram's six degrees of separation, but also to see what cultural, geographic, or attitudinal factors affect success rates. These are not questions that can be probed by scientific methods alone, so we enlisted the input of designers and artists in order to better explore the subjectivity of Burning Man's magic.

But what should the Vessels look like? We spent the summer leading up to the event talking to Burners in order to find out. We gleaned as much information as we could about the aspects of Burning Man that enable cooperation and creativity. For example, we learned that art at Burning Man is not passively observed like in a museum, but rather invites active interaction such as climbing, touching, or drawing. Often, this relationship is generative, taking on new interactions beyond the original intent of the artist. To capitalize on this, the final contents of each Vessel contained a disposable camera, a scroll, gift pendants, and a GPS tracker. These objects created a ritual of gift exchange and creative user participation, while providing incentives to keep the Vessels moving. The camera allowed each participant to contribute their experience to the project, while generating a visual record of each Vessel's journey. The pendants contained a web URL that allowed participants to access the project in its final form and provide valuable feedback on their experience. The GPS unit allowed us to see how the Vessels traveled across the desert, and to build a data-driven map of mobility.

The Vessel also contained a scroll resembling a Hebrew Torah with instructions for the experiment, the information for finding the Terminus, and

THE SCROLL Christian Almenar, holding the scroll. Each scroll contained information about the Terminus in the bottom left, as well as a place for each participant to add their own information.

MICAH EPSTEIN

the necessary context and disclosure. Based on our research into the Burning Man Glossary, we carefully mediated the writing style of the text, crafting a vernacular of ritual and removing words that were inaccessible or that seemed overly "default"—Burning Man's term for the outside world.

In order to select individuals as the destination for each Vessel, we collaborated with the *Burning Man Journal* on a broadcast that asked the Burning Man community to sign up for participation. We expected only a handful of people to be willing to help with the project. To our surprise, we were flooded with volunteers and offers of support, from people all over the world. From a single blog post, over 350 people offered to become a Terminus, giving us a diverse and representative subject pool. In their correspondence to us, Burners said things like: "Super excited for your project! I did my Ph.D. on network community structure. Would be thrilled to help assemble data and analyze." and "I'm excited to be involved with this project! Let's make it happen!"

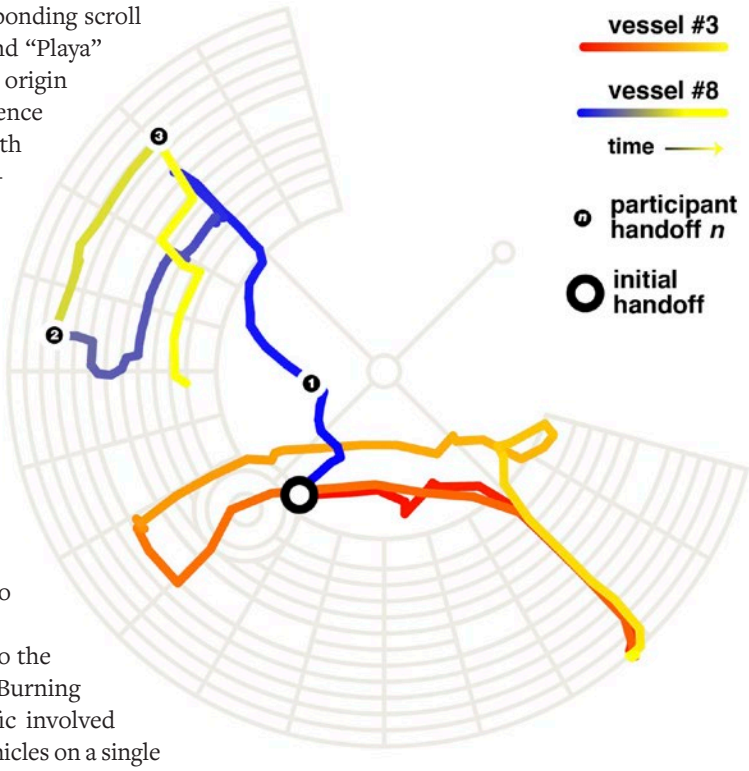
From that pool of 361 volunteers, we carefully choose our 15 final Terminii to mirror the demographic distributions of the larger Burning Man population on features such as age, origin, experience, and gender. Based on these criteria, we randomly selected 15 people in order to not introduce experimenter bias into the methods (for our full method, please see our research paper).[4]

For each Terminus, their corresponding scroll included their name (birth name and "Playa" name), their picture, their city of origin and their home city, and a brief sentence that described their interests. With the details provided, we were careful to share enough information so that the Vessel could be routed to someone closer, but not too much information (say, the Terminii's camp location) that would make social search trivial. One Terminus was a blue-bearded Burning Man Ranger with a flamethrower who drove around on a Cookie Monster art car. Another was an entomologist who wore wings and antennae. A third was a performer in his 70s who danced to EDM through the night.

On Aug. 27, 2018, we trekked into the desert in search of cooperation. Burning Man is known for the severe traffic involved with routing tens of thousands of vehicles on a single dirt road. In some cases, it can take eight hours to travel half a mile. But instead of the headache of urban traffic jams, we were greeted with something more akin to a decentralized party. Around us, people shared snacks and sunbathed on roofs—it was generally a good time.

The next morning, we activated the 15 GPS units, epoxied them into the Vessels, and went to Inner Playa—the central hub of Black Rock City—to launch our experiment. Along the way, we passed out pendants to the many curious passersby. We hoped the pendants would help to create a visible community of people associated with the project, building hype and visual presence on the Playa.

We arranged the Vessels to stand in a line. In true Burning Man fashion, we loudly made our presence known by heckling passersby. To the folks we assembled, we explained the nature of the experiment and asked them if they would like to contribute. Those who accepted the challenge became the first Cartographers. Over the course of one hour, we handed out all 15 Vessels and returned to camp to celebrate with a bowl of dusty chili.



THE TRACKER The Vessels each contained a GPS tracker, which allowed us to see how they moved across Burning Man. Although we were only to recover data for two Vessels, above you can see the mobility patterns and handoffs of Vessels 3 and 8 through time.

The scrolls stipulated that the Vessels should be returned to the Burning Man Lost and Found if the Vessel found its way to the Terminus, or if the event ended. After the dust and ash had settled at the end of the Burn, three Vessels found their way back to the Lost and Found and we grabbed them on our way out. We were exhausted from the long week, but excited to analyze the results.

WE RETURNED to the MIT Media Lab, and a few days later, strange packages started to arrive. It turns out two more Vessels had been turned into the Burning Man Lost and Found after we had left the Black Rock Desert. These Vessels had been kindly mailed back to us by the Lost and Found staff. After inspecting the five total

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Vessels, it seemed like our attempt at social search was unsuccessful. We reached out to all 15 Terminii to see if they had received their Vessel, and discovered that none of the Vessels successfully made its way to its Terminus.

We learned, however, that some of the Vessels got very close. One Terminus, a Black Rock Ranger, said that his Vessel found its way to the Ranger headquarters, and that he received a message to pick it up. When he went to retrieve it, however, the Rangers could not find the Vessel. It was eventually found, but not until the he had already left Black Rock City. Another Terminus said that one of his campmates, by the name of Mango, returned to camp with a Vessel for a different Terminus. Mango had been tasked to find someone else, driving a truck repurposed to look like a giant snail. Despite these close calls, it looked like cooperation had failed at Burning Man. The anarchic network of Burning Man was just that: anarchic. If there was a way to efficiently route information through the community, we didn't find it.

THE TERMINUS (Right to left) Ziv Epstein and Micah Epstein present Terminus #12 and her friend with her Vessel in Providence, Rhode Island, during the East Coast decompression event.

But it all changed one fateful day in October. "You won't believe this," an email from Terminus #11, a performer whose real name is Steve, read, "but I finally received the Vessel at Denver's Decompression last Saturday night! Everything looks to be intact, including the scroll, camera, and GPS unit at the bottom. How can I go about getting it back to you to be included in the Atlas?"

The Decompression event he was referring to is a key part of integrating back into regular life after Burning Man, by convening local burner communities all over the world to "celebrate and cope with re-entry." The person who had the vessel (and asked to remain anonymous) at the end of Burning Man was also from Denver, and figured while they couldn't get it to Steve on Playa, they could bring it home and try to find him in Colorado. According to Steve, they reached out to him on Facebook and met up at the Decompression event for the exchange. The scroll explicitly said that the last person with the Vessel should return it to Lost and Found. But the penultimate person in Steve's successful chain decided to ignore the rules and take the Vessel back to Denver with him, determined to find the Terminus. In the end, not only did the Vessel make its way to its Terminus in four hops, but it also crossed state borders to do so. By the time Steve's Vessel made it back to us in Cambridge, Massachusetts, all the pendants were gone, but in return it was packed full of Burning Man gifts: stickers, headbands, and dust.

Serendipity struck once again when we made our way to the Decompression event in Providence, Rhode Island. We had casually brought with us a couple of the unclaimed Vessels from Lost and Found to the Decompression, just to show people what we had been working on. Lo and behold, we were chatting a friendly woman, explaining the project, when her demeanor quickly changed. "Wait, I think I'm part of this project!" We ourselves had found Terminus #12! And even more incredibly, one of the Vessels we had brought was destined for her. We presented Terminus #12 with her Vessel, and inadvertently become the penultimate

UNKNOWN PHOTOGRAPHER

links in the six-person chain that got the vessel to its terminus. We, the researchers, had accidentally found Terminus #12, not in the desert, but on the other side of the country, on a cold Providence night.

When we started on this journey, we expected to cleanly measure the efficiency of a social network, just as Milgram had done over 50 years ago. We thought charting the Vessels' routes would be as straightforward as collecting the Vessels and calculating the rate of return based on the chain lengths. But that's not what we discovered at Burning Man. We learned something more valuable.

In our commercial society, networks are designed for efficiency and growth. They are configured for optimal routing. Be there on time, don't wander, profits depend on it. The same is true for what has become of the Internet. Optimists envisioned it as a decentralized network of individuals that could upend the hierarchies of government and corporations. But today dominant sites, built on proprietary algorithms and overrun by advertising, have commodified personal identity and reinforced political echo chambers.

At Burning Man, we got a powerful glimpse of a social network that breaks the chains of techno-bureaucracy. We saw a network that champions cooperative effort and whimsical creativity over efficiency. These values create a unique context where unexpected optimism and serendipity are the norm. Our experiment showed us what people can be when freed from circumscribed networks, and that vision burns bright. We can design social networks—our communities, our institutions, and our communication platforms—to embody the cooperative and optimistic spirit that affirms our humanity. Cooperation doesn't have to be forced on us, it can come from within us. That's how a desert is cleaned. And how a Vessel finds its way home.

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We saw a network that champions cooperative effort and whimsical creativity over efficiency.

Playing Video Games Makes Us Fully Human

No other media meets our emotional and social needs like electronic games

BY BRIAN GALLAGHER

LIBBABINK / FLICKR

I HAVE AN AGONIZING DECISION to make. Should I save a governing body that has never done a thing for me? It doesn't even contain a single person from my race. The aliens of the galactic Council decided long ago that my people should not be trusted, that we were aggressive, entitled, and short-sighted. I'm a soldier engaged in a fight to save the entire galaxy. And now the Council wants my help to destroy their assailants? My companion Ashley is against it. "You can't sacrifice human lives to save the Council!" she yells. "What have they ever done for us?" Another companion, Garrus, rebuffs Ashley. "This is bigger than humanity!" *Schadenfreude* tempts me to let the patronizing Council be pulverized; a pro-human one could replace it if we survive. But I don't want to give cynical aliens an opportunity to attribute the lowest-possible motive to humans. I want to refute the impression that we are an arrogant, upstart species out for itself. I command humanity's space armada to target the forces gunning for the Council, no matter the cost. I feel a rush of bravery and idealism. I love playing Mass Effect.

I'm not alone. The popularity of video games is staggering. Last year, the top 25 public game companies—China's Tencent, Sony, and Microsoft ranking highest—had annual earnings of more than $100 billion for the first time.[1] The United States video game industry earned more than global box office movie ticket sales, U.S. video streaming subscriptions, and the U.S. music industry.[2] By 2021, according to Statista, a market research firm, 2.7 billion people will be playing video games, up from 1.8 billion five years ago. A Pew survey reveals the age group that plays most often is 18 to 29.[3] In the 30 to 49 age group, nearly 50 percent of men and 40 percent of women play. A study in Europe shows people 45 and up are more likely to play video games than children aged 6 to 14.

I wouldn't blame you for thinking video games are like potent drugs, offering escapist fantasies that deprive teenagers of sleep and food until they are strung out and incapable of functioning in the real world. There have certainly been enough horror stories in the psychological literature over the years to raise concern that video games are eating the brains of the world's youth. But this negative portrait is outdated.

Pete Etchells, a professor of psychology and communications in England, and author of a new book, *Lost in a Good Game*, thinks video games tap into the reaches of emotional and moral faculties that traditional arts and entertainment can't reach. The player can drive action, exert agency, and explore imagined worlds freely. Video games, Etchells says, "embody the principles of existentialism." A story can be cathartic but only a game can make you feel guilty for what you've done or were compelled to do. A 2010 paper in *Review of General Psychology* states, "Compared with other media such as books, films, and radio, electronic games appear to have an unusually expansive appeal and serve a surprising number of emotional, social, and intellectual needs."[4] For Etchells, an avid gamer, video games are a "creative medium" that can "offer us unparalleled opportunities for exploring what it means to be human."

IN THE PAST DECADE, the study of video games and their effects has become a veritable wing of psychology departments. Leading the defense is "self-determination theory." The theory was conceived in the 1980s by two psychologists at the University of Rochester, Richard Ryan and Edward Deci. In their 2017 book, *Self-Determination Theory: Basic Psychological Needs in Motivation, Development, and Wellness*, they explain self-determination is what "humans really need from their psychological and social environments to be fully functioning and thrive."

Ryan and Deci say that this boils down to competence, autonomy, and relatedness. Mastering something, feeling free to follow your interests and values, and having ways to bond with others give you the sense you are living well—no matter your cultural heritage. People everywhere—Europe, Asia, South America—need these things like they need vitamin C, Ryan and Deci say. Since we evolved to be "inherently curious, physically active, and deeply social beings," Ryan and Deci write, we are intrinsically motivated to "take an interest in, learn about, and gain mastery with respect

to both [our] inner and outer worlds," the social and physical. We thrive when we realize our human capacities and overcome the forces that might stultify us.

In a series of studies investigating the motivational pull of video games, Ryan, with psychologists Scott Rigby and Andrew Przybylski, write that video games activate intrinsic motivation, the drive we feel to do something for its own sake.[5] The more potential for competence and autonomy gameplay affords, the more we will feel motivated to pursue and engage in it.[6] Presence, or a sense of immersion, is crucial, too, and hinges on how competent and autonomous the game makes you feel (having intuitive game controls helps). The psychologists expected playing video games would make a fine test of their theory because it addresses "fundamental psychological and motivational dynamics rather than deconstructing specific instances of games or genres."

A story can be cathartic, but only a game can make you feel guilty for what you've done.

The researchers assessed the players' moods, self-esteem, vitality (a sense of energy or aliveness), game enjoyment, and preference for future play. You might recognize many of the games the researchers had subjects play: Nintendo's Super Mario 64 was one of them. Of course, not everyone is a fan of Mario, even in three dimensions, and some subjects weren't intrinsically motivated to play (they were there for extra course credit), so most of the 90 subjects (a majority of them women), after playing Mario, chose to switch games rather than continue and, on average, felt less energized. The people who kept playing were the ones who felt a sense of competence and increased well-being from pre- to post-play. With The Legend of Zelda: Ocarina of Time and A Bug's Life, players got to experience the difference between a good and bad game—the former (an action-adventure game allowing players lots of leeway in exploring the in-game world) being widely considered one of the greatest games of all time, and the latter (based on a movie) not so much. Zelda was more enjoyable, immersive, and motivating than A Bug's Life due to the greater sense of mastery and autonomy it offered players. A Bug's Life had easier-to-learn controls, but for mastery of the controls to be "associated with positive effects," the researchers found, it seems like players must have opportunities to satisfy their needs.

To tease out the motivations a person might have for playing different sorts of games, Ryan and his colleagues had people play generally well-received games like Super Mario 64, Super Smash Bros., Star Fox 64, and San Francisco Rush. Rush is an arcade-style racing game; in Star Fox, you play as an anthropomorphized fox who pilots a starfighter; and in Smash Bros., you fight against computer-controlled opponents and win by knocking them off the fighting stage, usually by inflicting lots of damage, which increases how far your attack sends an enemy flying. People varied widely on whether they considered the games enjoyable or motivating to play, and there was no consensus on the sort of game they preferred. But players' in-game need satisfactions accounted for all these differences. Finding their preferences for competence and autonomy led subjects to "greater enjoyment and sense of presence and increased preference for future play," the researchers wrote. "When individuals played games where they experienced competence satisfactions they also experienced increased vitality, self-esteem, and positive affect, whereas individuals who were generally more autonomous in their playing experienced overall higher self-esteem and positive mood, and more value for the game."

Ryan and his colleagues probed the influence of social connection by advertising a modified version of the survey they used in the previous studies—slightly shortened but with new questions about socializing—in an online community forum, whose members discuss video games, among other things. If members would answer questions about their experience playing MMO (Massively Multiplayer Online) games, they'd be entered into a raffle to win a six-month subscription for a game of their choosing, around a $75 value. Over 700 people, overwhelmingly male and ranging in age from 16 to 44, took the survey. Satisfying needs for

LOST IN A GOOD GAME People immersed in their favorite games can seem under the sway of a potent drug, but that's an outdated perspective. Video games capture our attention because they engage basic human emotions tied to mastery and autonomy.

ARMAGANERGUNEY / SHUTTERSTOCK

competence and autonomy accounted for the players' enjoyment and motivation to play—but relatedness was a big factor, too. Feeling socially connected to other players contributed to the subjects' enjoyment but also to their sense of presence and intention to continue playing in the future.

Etchells writes that this series of studies "provided an incredibly useful experimentally based starting point for thinking about the specific factors underlying why people find different sorts of games enjoyable, as well as what motivates them to start, or continue playing them." The idea that competence, autonomy, and relatedness contribute to a fun experience "makes intuitive sense." If a game's controller and mechanics are cumbersome it will be difficult to manifest a feeling of mastery, which also takes you out of the experience of the game—you're too ensconced on what your fingers are doing rather than feeling like your avatar is a seamless extension of yourself.

A 2016 study from researchers at the University of Saskatchewan led by Max Birk, now an assistant professor in the Department of Industrial Design at Eindhoven University of Technology, applied Ryan and his colleagues' "player experience of needs satisfaction" measure to the task of creating an avatar for a video game, and using that avatar in gameplay.[7] Greater

I find myself thinking I want to be more like my character—someone brave, curious, and unrelenting.

identification with the avatar "predicted increases in autonomy, immersion, invested effort, enjoyment, and positive affect," they wrote. Identification with the avatar, in their study, depended on the player feeling similar to, and embodied within, the avatar, as well as wishing he or she could be more like it.

Cognitive science has detailed the rich experience of playing video games. A 2017 paper analyzed 116 scientific studies of video game effects, and the conclusions were impressive.[8] Yes, video games can become a fixation, but gamers tap into brain areas associated with improved attention spans, visuospatial skills, and motor systems more effectively than non-gamers. Further studies have argued that playing video games can help overcome depression and improve memory.

IN *LOST IN A GOOD GAME*, Etchells admits delving into the science of video gaming has caused him to think deeply about his own love of gaming. The same goes for me. As a 5-year-old, I'd equip my Playstation and Mortal Kombat Trilogy—a gleefully gory fighting game, rated "M" for mature—during stays at my grandparents' house, which appalled them, but amused me. I haven't put the controller down since.

Like Etchells, video games take me to places that music and movies, as much as I love them, don't. More to the point, they allow me to explore on my own. Video games "tap into that deeply-seated human desire to travel, seek out new experiences, and absorb new knowledge about the world—and about ourselves," Etchells writes. They free us to explore unfamiliar emotional and geographical territory and learn new things without too much fear or anxiety. Video games "provide a safe place where we can relax as digital tourists within the comfort of our own home, visiting places that might only otherwise be accessible in the wildest reaches of our imagination." I might go further and say traveling in imaginary spaces rivals the experiences of traveling

in real ones, like Venice and Rome, Lima and Machu Picchu, as I have in my life. Both the imaginary and real are emotionally moving and immersive.

"Like the ancient human city of Troy," the in-game Mass Effect encyclopedia informs me, "Ilos is a world known only through second-hand sources." Not anymore. I walk among the vegetation-covered ruins of one of Ilos' many metropolises, built by an ancient and advanced people known as the Protheans. I'm told by a left-behind Alexa-like intelligence named Vigil that it's here the Protheans made their last stand against a superior, genocidal enemy which Vigil knew would threaten the galaxy again. "You are safe here, for the moment," Vigil tells me. "But that is likely to change. Soon, nowhere will be safe." The moment is scored perfectly: I feel the awe of speaking to a bygone empire's last remnant, learning from it how to avoid their mistakes and save the galaxy.

Casey Hudson, the project director of Mass Effect, has said something that stuck with me and made me think about the lasting effects of video gaming. Video games provide an opportunity to ruminate on, even brood over, how to act in morally ambiguous or treacherous situations. That was "always a focus for us on Mass Effect," Hudson said.[9] "We would try to write those things in ... Players would later talk about how they would be in a certain situation in the game and really agonize about what they should do. They would put the controller down and really think about what they would want to do."

Has playing video games helped guide my own life? Can it? When I put the controller down and reflect on playing Mass Effect, I think about my motivation to learn about my human and alien companions, who each have rich backstories and complex feelings and desires. I realize I'm drawn to unexplored and dangerous planets, seeking new resources and knowledge. I find myself thinking I want to be more like my character—someone brave, curious, and unrelenting. I can make a difference. If not on a galactic scale, perhaps on my block. It's a place to start.

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We're More of Ourselves When We're in Tune with Others

Music reminds us why going solo goes against our better nature

BY KEVIN BERGER

WHEN MUSICIANS HAVE CHEMISTRY, we can feel it. There's something special among them that's missing when they perform alone. Anyone who's heard a Mick Jagger solo album knows that's the case. Clearly nature wants us to jam together and take flight out of our individual selves. The reward is transcendence, our bodies tell us so. What's the secret of that chemistry?

It's a question that one of the most refreshing neuroscientists who studies music has been probing lately. Refreshing because her lab is not only in academia but also on stage, where she performs as an opera singer and with chamber ensembles. Talking to Indre Viskontas is a treat because she animates her research as a scientist with her experiences as an artist. She breaks down the symphony of brain activity in the language of singing lessons and rehearsals.

In a recent interview, as Viskontas and I delve into the chemistry among performers, and the brain circuitry behind it, it becomes clear we're talking about more than music. The qualities that make a great band, she is saying, represent a harmony in all of us, waiting for expression.

Somewhere along the way of growing up in Toronto, the daughter of Lithuanian parents, where music was the daily bread (her mother is a choral conductor), Viskontas must have discovered she was a natural explainer, and nourished that skill with singing. She earned a Ph.D. in cognitive neuroscience from the University of California, Los Angeles, in 2006. Today she's the creative director of a small opera company in Pasadena, California; hosts a podcast, Cadence, on music and the mind; and just published a short book, *How Music Can Make You Better*. Her day job is as a professor of humanities and sciences at the San Francisco Conservatory of Music.

Viskontas tells me her inspiration to study the interplay among musicians arose out of her experiences. "Playing in ensembles is the whole reason I wanted to be a musician," she says. "It's just a magical feeling. It made me realize that whatever's happening when we're in sync, we're exchanging a lot of intuitive information, and we use that to feed off each other. It has that intangibility, the stuff that happens below the level of consciousness that we're all fascinated by. It's also a different way to think about creativity. How is it that when musicians come together, they produce this wonderful product?"

When you're in sync with somebody, are you activating parts of your brain that are dormant when you're alone? "Yes, the evidence suggests that's the case," Viskontas says. "Here's an analogy. If you forget somebody's name, the more you think about it, the harder it is to access. The name isn't dormant. Access to it is blocked because your conscious cognitive resources are going in a different direction. When you start thinking about something else, or leave a room, it pops into your mind. The same can be true for being alone. When you're alone and intensely focused on something, you've got an inner critic going, you're monitoring yourself. When you have to respond to somebody else, and allow yourself to hear other thoughts, you forget the inner critic. You hear other parts of your brain talking more loudly, more clearly. If you're a solo performer, it's really hard to get completely immersed in what you're doing. When you have to respond to somebody else, it's easier to forget your inner critic."

In her early years as a singer, Viskontas says, she had a tough time silencing her inner critic. "One of the things we work on as sopranos is that when we have to sing a high note, we want to float it, we want it to be completely free, but also have a real arc in terms of dynamics," she says. "There were times when I tried to do it in rehearsal and couldn't find the freedom in my voice that I wanted. Then all of a sudden in performance I feel like I have way more stamina, way more flexibility, and I can express that phrase much more the way that I want to than I ever did in rehearsal."

Nobody at a concert remarks, "This is totally stimulating my amygdala and insula!"

What's going on in performance? "Allow me to deep-dive into the brain for a minute," she says. "The left hemisphere, the part of your brain responsible for language comprehension, Wernicke's area, is connected to the part responsible for speech production, Broca's area, by a fiber tract called the arcuate fasciculus. When you're trying to repeat a word someone else has said, trying to express yourself, you want the left part of your brain comprehending what's coming in. Then you send that information to the production area, which figures out what you're going to say, and sends the information to the motor regions, which activate the muscles and allow you to speak. For most people, the arcuate fasciculus on the right side is a lot thinner than it is on the left side. Except for singers. As singers develop their vocal ability, that fiber tract gets thicker. They have more connections. What's happening is a singer is better able to hear something and produce it vocally, presumably using this right arcuate fasciculus. And that has a direct connection to how you are able to use your musculature."

"This is a long preamble to say that when you are performing with other people, you can tap into these connections, these pathways you've developed. Because there is an interplay between conscious control and more automatic responses in your brain and body, there are times when you can get in your own way. Your musculature can get in the way of the sound everybody wants to hear—one that's easy and free and sounds like it's coming from a soulful place, rather than you're manipulating it."

And how does she get to the soulful place? "I love working with string players," she says. "For a long time, most of my training was with a pianist. When you're performing with a piano, it feels percussive. There's a beginning and an end that are abrupt. And that's not good for breathing. You want breathing to be an organic process that opens and closes. I remember the first time I sang with a string orchestra. It completely relaxed my approach to breathing and made me a better singer. I was like, 'Oh, that's how I need to play my vocal cords. I can't just play them like a piano, I need to play them like a violin, where I'm coaxing, rather than pushing, the sound out of them.' "

"In terms of biology, you make a sound by bringing your two vocal cords together and apart. If you don't have tension, your vocal cords come together in ways that are supple and gentle. As a singer, you want them to kiss softly. The sound comes from the breath. When I sing with a string orchestra, we all have to breathe together. That breath becomes the music."

STAGE MAGIC Indre Viskontas—here as the Countess in Mozart's *Le Nozze di Figaro*—says live performance brings out the best in her voice. "You want it to sound like magic," she says.

INTERNATIONAL LYRIC ACADEMY OF ROME

SOUND OF SYMPATHY "The way we interact with music is in line with developing empathy and how we put ourselves in the shoes of the musician," says Indre Viskontas, here with the chamber ensemble, Vocallective.

SAN FRANCISCO CONSERVATORY OF MUSIC

AT THE SAN FRANCISCO CONSERVATORY OF MUSIC, Viskontas is conducting a series of experiments called The Ensemble Project to learn how musicians can play the most evocative and moving music together. In a recent experiment, followed by an article in the journal *Behavioral Sciences*, Viskontas, Matthew Slayton, and Adam S. Bristol varied the conditions in which six musicians played a chamber piece.[1] The conditions include seeing one another but avoiding direct gazes, playing with no gestures and strictly by tempo markings, and not seeing one another at all. When the musicians see each other but avoid direct gazes, "they feel less connected and the performance is less coordinated." When they play with technical strictures, they also feel the music suffers. When they can't see each other at all, they rely more on auditory cues and are less distracted by their context, "making the performance feel more intimate."

Viskontas' Ensemble Project is informed by a satchel of studies that journey into the brain to see what neural networks are and aren't firing when performers are in the flow of music. In 2012, Charles Limb, a neuroscientist and surgeon now at the University of California, San Francisco, led a study that asked professional jazz musicians to jam on a special keyboard in a functional MRI scanner.[2] When the musicians were in the groove, improvising, their medial prefrontal cortex, responsible for fashioning a sense of self and internal motivation, was alight. Meanwhile, their lateral orbitofrontal cortex and dorsolateral prefrontal cortex, which monitor, evaluate, and correct goal-directed behaviors, deactivated. Their inner critics were chilling, allowing "spontaneous unplanned associations, and sudden insights or realizations" to flourish. When the jazz players injected emotion into the notes, they stirred connections among the limbic and paralimbic areas, such as the amygdala and

insula. Limb and his fellow researchers conclude that performing with emotion stirs a bounty of neural connections that allow musicians to slip into flow states, where inhibitions give way to pleasure and freedom, keys of creativity.[3]

Germane to Viskontas' work, neuroscientists have shown that music releases the social-bonding chemicals in our brains and bodies. Playing and hearing music, one 2014 study relates,[4] engages the "endogenous opioid system," releasing a cascade of neurohormones—oxytocin and vasopressin, dopamine and serotonin—bequeathed to us by nature to draw us into protective enclaves, fall in love, and keep the genes going. When musicians feel connected, they communicate better and read one another's gestures more clearly. Good communication allows them to "respond to performance errors or perturbations flexibly, by expanding their cognitive effort and moving away from a rote performance," Viskontas, Slayton, and Bristol write. Poor coordination, meanwhile, can arouse musicians' lateral prefrontal cortex regions to impose control and ground them before they can take flight.

Slayton, a classical music composer who recently graduated from the San Francisco Conservatory of Music, tells me about one of the most eye-opening studies behind his and Viskontas' recent paper.[5]

The study separates individuals into high and low creative groups. (Creativity is measured by participants' ideas for alternative uses of everyday objects.) Each of the pairs is given the same hypothetical problem to solve. The surprising result is that pairs of less-creative individuals perform as well as pairs of high-creative individuals. Being in sync shows up in their brain scans, which reveal increased activity in prefrontal regions correlated with cooperative behavior and group creative performance. The study underscores what good chemistry among musicians means. Individual band members may not be the best musicians, compared to others, and may not be the best musicians when they perform alone. But when they come together, they are, well, the Beatles.

OUT OF YOUR HEAD "Performing with others, being on stage, can get help us out of our heads and to that place where we just rely on our intuition," says Indre Viskontas, here as Micaela in *La Tragédie de Carmen*.

ADAM ISAAK

"The more tightly the social parts of our brain are connected, the more possible it is that performance will be more moving, more expressive," Slayton says. "Brains are social, people are social, and when they're connected, that has the best effect for creativity." Slayton offers that understanding the social nature of brains spurred him to reflect on his own music. "To be honest, I used to be more interested in heady concerns that only other composers would care about," he says. "Many people use music for expression and communication of something personal, and I never related to that. But the more I've learned about how brains connect, about emotional synchrony, I've been thinking more about how a listener will respond, about the emotional impact music will have on the listener."

When you have to respond to somebody else, it's easier to forget your inner critic.

Having natural chemistry with others is wonderful, Viskontas says. But it doesn't have to follow the romantic script of being something you either have or don't have with them. It can be developed in rehearsal.

"If you feel in sync with the rest of the group, that's great; you don't have to worry about whether the next time you demonstrate a downbeat, they're going to pick it up," Viskontas says. "But sometimes it just takes a few rehearsals for you to say, 'Oh, I get it, when you're setting the pulse, it's in the way your chest is moving.' So you do it again until you agree on what the pulse is in this particular measure. Now you're starting to know the other person better, you're starting to read their gestural language better. Conductors often practice in front of a video camera or mirror. They look at themselves and ask, 'Was it clear what I was trying to show? Are my body gestures indicating what it is that I think they are?' It's like practice in any other athletic or physical endeavor."

Viskontas says the brain chemistry among musicians is also what gets listeners high. "The way we interact with music is very much in line with developing empathy, and how we put ourselves in the shoes of the musician," she explains. "Our brains mirror what we're seeing. So when we're in sync, many of the rhythms of our brains and bodies entrain—heart and respiration rates, certain brain wave patterns. When you're moved by music, we see levels of the attachment-hormone oxytocin increase. People who sniff oxytocin before they play together are more in sync rhythmically. For all of us, these neurochemicals make us more attuned to the signals we use to understand each other's behavior."

I say to Viskontas that her research into the neurobiology of music is great for science journals. But what's it done for her as a singer? She laughs, and answers that it's helped her lure audiences into her vocal lair.

"My teacher used to say, 'Indre, all the notes leading up to the high note are important. The high note doesn't matter.' I would say that's nuts. They're paying me for the high note. If I screw up the high note, everyone will remember. Then I read research about how the caudate nucleus, the 'wanting' part of your brain, tracks. There's more dopamine in that area as you're anticipating the climax of a musical piece. Once you get to the climax, you get a boost of dopamine in the nucleus accumbens, which is the 'liking' part of the brain. When I read that, I learned why all the notes leading up to the high note matter more."

She continues: "If you don't take the audience on a journey, showing them that just around the corner is this awesome thing, they won't enjoy it as much. I used to think that I just need to feel the emotion and the audience will get it. Then I realized, 'No, I need to be a magician.' If I went on stage and there was silence before I started to sing, I would think, 'I need to get going, the audience is getting bored!' Now I realize the longer I can extend the silence, the better. I just stand up there and luxuriate in the tension that I'm creating by not singing. So that's what I got from neuroscience, the insight that I need to get the audience's brain in the right mode to enjoy what I'm about to do."

VISKONTAS AND I AGREE that reducing music to neurobiological activity leaves us feeling unsatisfied. Nobody at an amazing concert remarks, "This is totally stimulating my limbic and paralimbic areas, especially the amygdala and insula!" The language of neuroscience undermines the richness of lived experience.

But what's remarkable about hearing from the artist about biology is the reminder of what our brains are capable of, maybe something we've forgotten, or never known. When we're in sync with others, we silence the critic in our brains, allow emotions to stir new neural connections, and become "more aware of our sensory environment," Viskontas says. This mental state allows musicians to tap the flow of their fellow performers and create sounds they couldn't shape alone. It's a harmony that resounds beyond the concert hall.

"The pleasure and meaning we get from playing in sync underscores how rewarding it is when we feel connected to others," Viskontas says. "There's no *a priori* reason why this should be pleasurable—the way other drives like hunger and thirst yield pleasure because they keep us alive. But it's more interesting than that. It gives us the suggestion that there is more to life than just ourselves. The pain of social isolation shares neural underpinnings with physical pain. But the sense of belonging is comforting. It's akin to a religious experience, where you feel the ecstasy of finding meaning in connecting with what you believe is a higher power."

For many of us, music is that higher power. "It allows us to communicate with each other in ways that transcend language, in ways that transcend these other kind of barriers we have," Viskontas says. "It allows us to understand each other in ways that no other medium does."

KEVIN BERGER is the editor of *Nautilus*.

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"IN MATHEMATICS, MISTAKES AREN'T WHAT THEY USED TO BE"

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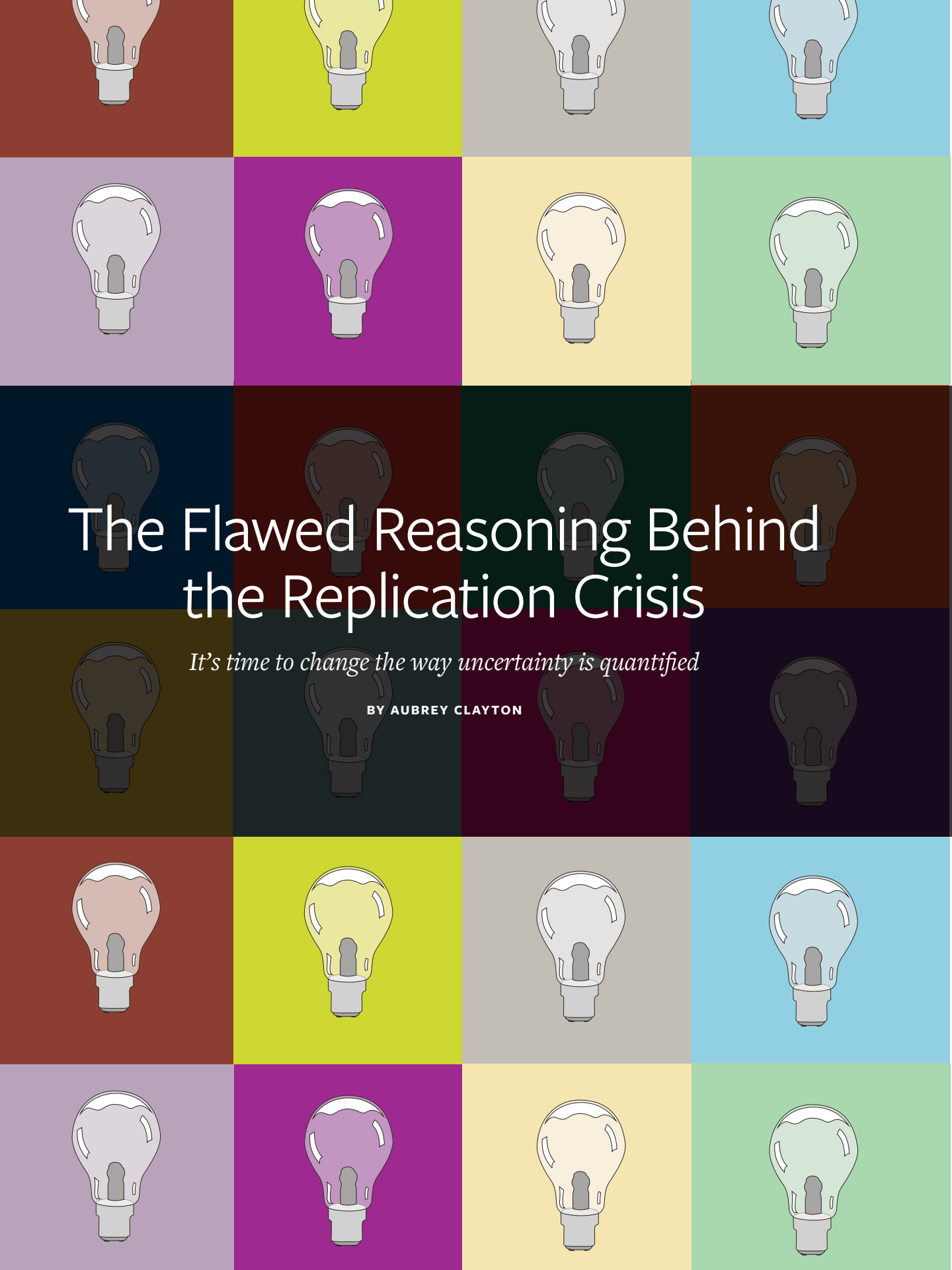

The Flawed Reasoning Behind the Replication Crisis

It's time to change the way uncertainty is quantified

BY AUBREY CLAYTON

HERE ARE THREE VERSIONS of the same story:

1 **IN THE FALL OF 1996,** Sally Clark, an English solicitor in Manchester, gave birth to an apparently healthy baby boy who died suddenly when he was 11 weeks old. She was still recovering from the traumatic incident when she had another baby boy the following year. Tragically, he also died, eight weeks after being born. The causes of the two children's deaths were not readily apparent, but the police suspected they were no coincidence. Clark was arrested and charged with two counts of murder. The pediatrician Roy Meadow, inventor of the term "Munchausen Syndrome by Proxy," testified at the trial that it was extremely unlikely that two children from an affluent family like the Clarks would die from Sudden Infant Death Syndrome (SIDS) or "cot death." He estimated the odds were 1 in 73 million, which he colorfully compared to an 80:1 longshot winning the Grand National horse race four years in a row. Clark was convicted and sentenced to life in prison. The press reviled her as a child murderer.

2 **SUPPOSE AN OTHERWISE HEALTHY WOMAN** in her 40s notices a suspicious lump in her breast and goes in for a mammogram. The report comes back that the lump is malignant. She wants to know the chance of the diagnosis being wrong. Her doctor answers that, as diagnostic tools go, these scans are very accurate. Such a scan would find nearly 100 percent of true cancers and would only misidentify a benign lump as cancer about 5 percent of the time. Therefore, the probability of this being a false positive is very low, about 1 in 20.

3 **IN 2012, PROFESSOR ARA NORENZAYAN** at the University of British Columbia claimed to have evidence that looking at an image of Rodin's sculpture *The Thinker* could make people less religious. In a trial of 57 college students, he randomly assigned participants to view either *The Thinker* or a control image, Myron's *Discobolus*, a sculpture of a Greek athlete throwing a discus, and then rate their belief in God on a scale from 1 to 100. Subjects who had been exposed to *The Thinker* reported a significantly lower mean God-belief score of 41.42 vs. the control group's 61.55. The probability of observing a difference at least this large by chance alone was about 3 percent. So he and his coauthor concluded *The Thinker* had prompted their participants to think analytically and that "a novel visual prime that triggers analytic thinking also encouraged disbelief in God."

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Atheists hailed it as scientific proof that religion was irrational; religious people were understandably offended.

All three of these vignettes involve the same error in reasoning with probabilities. The first two are examples of well-known fallacies, called, respectively, the Prosecutor's Fallacy and the Base Rate Fallacy. The third is a typical statistical analysis of a scientific study, the kind you can find in most any reputable journal today. In fact, Norenzayan's results were published in *Science* and have to date been cited some 424 times in research literature. Atheists hailed it as scientific proof that religion was irrational; religious people were understandably offended at the suggestion that the source of their faith was a lack of reasoning ability.

The failure in reasoning at the heart of the three examples points to why so many results, in fields from astronomy to zoology, cannot be replicated—a big problem that the world of science is currently turning itself inside out trying to deal with.

THE MATHEMATICAL LENS that allows us to see the flaw in these arguments is Bayes' theorem. The theorem dictates that the probability we assign to a theory (Sally Clark is guilty, a patient has cancer, college students become less theistic when they stare at Rodin), in light of some observation, is proportional both to the conditional probability of the observation assuming the theory is true, and to the prior probability we gave the theory before making the observation. When two theories compete, one may make the observation much more probable, that is, produce a higher conditional probability. But according to Bayes' rule, we might still consider that explanation unlikely if we gave it a low probability of being true from the start.

So, the missing ingredient in all three examples is the prior probability for the various hypotheses. In the case of Sally Clark, the prosecution's theory was she had murdered her children, itself an extremely rare event. Suppose, for argument's sake, by tallying up historical murder records, we arrived at prior odds of 100 million to 1 for any particular mother like her to commit double infanticide. That would have balanced the extreme unlikelihood of the observation (two infants dying) under the alternative hypothesis that they were well cared for. Numerically, Bayes' theorem would tell us to compare:

(1/73,000,000) * (99,999,999/100,000,000) vs. (1) * (1/100,000,000)

We'd conclude, based on these priors and no additional evidence aside from the children's deaths, that it was actually about 58 percent likely Clark was innocent.

For the breast cancer example, the doctor would need to consider the overall incidence rate of cancer among similar women with similar symptoms, not including the result of the mammogram. Maybe a physician would say from experience that about 99 percent of the time a similar patient finds a lump it turns out to be benign. So the low prior chance of a malignant tumor would balance the low chance of getting a false positive scan result. Here we would weigh the numbers:

(0.05) * (0.99) vs. (1) * (0.01)

We'd find there was about an 83 percent chance the patient doesn't have cancer.

Regarding the study of sculpture and religious sentiment, we need to assess the likelihood, before considering the data, that a brief encounter with art could have such an effect. Past experience should make us pretty skeptical, especially given the size of the claimed effect, about a 33 percent reduction in average belief in God. If art could have such an influence, we'd find any trip

HUNG CHUNG CHIH / SHUTTERSTOCK

THOUGHTLESS A study claiming that gazing at Rodin's famous work, *The Thinker*, improved analytic thinking and discouraged belief in God, is one of many exhibits in the replication crisis.

to a museum would send us careening between belief and nonbelief. Or if somehow *The Thinker* wielded a unique atheistic power, its unveiling in Paris in 1904 should have corresponded with a mass exodus from organized religion. Instead, we experience our own religious beliefs, and those of our society, as relatively stable through time. Maybe we're not so dogmatic as to rule out *The Thinker* hypothesis altogether, but a prior probability of 1 in 1,000, somewhere between the chance of being dealt a full house and four-of-a-kind in a poker hand, could be around the right order of magnitude.

Norenzayan's data, which he claimed was unlikely to have arisen by chance, would need to be that much more unlikely to shake us of our skepticism. According to the study, the results were about 12 times more probable under an assumption of an effect of the observed magnitude than they would have been under an assumption of pure chance. Putting this claim into Bayes' theorem with our prior probability assignment would yield:

(12 p) * (1/1,000) vs. (p) * (999/1,000)

We'd end up saying the probability for *The Thinker*-atheism effect based on this experiment was 0.012, or about 1 in 83, a mildly interesting blip but almost certainly not worth publishing.

THE PROBLEM, THOUGH, is the dominant mode of statistical analysis these days isn't Bayesian. Since the 1920s, the standard approach to judging scientific theories has been significance testing, made popular by the statistician Ronald Fisher. Fisher's methods and their latter-day spinoffs are now the *lingua franca* of scientific data analysis. In particular, Google Scholar currently returns 2.85 million citations including the phrase "statistically significant." Fisher claimed significance testing was a universal tool for scientific inference, "common to all experimentation," a claim that seems borne out by its widespread use across all disciplines.

Fisher hated Bayesian inference with a passion and considered it a great historical error, "the only mistake to which the mathematical world has so deeply committed itself." As a result, his methods don't have any place for prior probabilities, which he argued weren't necessary to make inferences. Significance testing only uses the probability of the data assuming a hypothesis is true, that is, only the conditional probability part of Bayes' rule. If the observed data (or more extreme data) would be very unlikely under a hypothesis, usually the "null hypothesis" of no effect, the data is deemed "significant" and considered sufficient evidence to reject the hypothesis.

Defending the logic of this approach, Fisher wrote, "A man who 'rejects' a hypothesis provisionally, as a matter of habitual practice, when the significance is at the 1 percent level or higher"—that is, when data this extreme could only be expected 1 percent of the time—"will certainly be mistaken in not more than 1 percent of such decisions. For when the hypothesis is correct he will be mistaken in just 1 percent of these cases, and when it is incorrect he will never be mistaken in rejection."

However, that argument obscures a key point. To understand what's wrong, consider the following completely true, Fisherian summary of the facts in the breast cancer example (no false negatives, 5 percent false positive rate):

> Suppose we scan 1 million similar women, and we tell everyone who tests positive that they have cancer. Then, among those who actually have cancer, we will

> be correct every single time. And among those who don't have it, we will be only be incorrect 5 percent of the time. So, overall our procedure will be incorrect less than 5 percent of the time.

Sounds persuasive, right? But here's another summary of the facts, including the base rate of 1 percent:

> Suppose we scan 1 million similar women, and we tell everyone who tests positive that they have cancer. Then we will have correctly told all 10,000 women with cancer that they have it. Of the remaining 990,000 women whose lumps were benign, we will incorrectly tell 49,500 women that they have cancer. Therefore, of the women we identify as having cancer, about 83 percent will have been incorrectly diagnosed.

Imagine you or a loved one received a positive test result. Which summary would you find more relevant? By ignoring the prior probability of the hypothesis, significance testing does the equivalent of diagnosing a medical condition based only on how often a patient would test positive if the condition were absent, or of reaching a legal verdict based only on how unlikely the facts of the case would be if the suspect were innocent. In short, significance testing would have told our hypothetical patient that she probably has cancer and would have wrongfully convicted Sally Clark.

Significance testing has been criticized along these lines for about as long as it's been around. William Rozeboom, a professor of psychology at St. Olaf College, wrote in 1960 that the true logic of scientific inference was "inverse probability," a.k.a. Bayes' theorem. In 1966, David Bakan of the University of Chicago Department of Psychology referred to the logical fallacy of significance testing as something "everybody knows" but nobody would admit out loud, as in the story of the emperor's new clothes. In 1994, the statistician Jacob Cohen wrote a scathing critique called "The Earth Is Round ($p < .05$)," arguing that significance testing had things backward by focusing only on the probability of the data given a hypothesis instead of the hypothesis given the data. Falk and Greenbaum[1] called this the "illusion of probabilistic proof by contradiction" or the "illusion of attaining improbability," and Gigerenzer[2] called it the "permanent illusion."

In the case of Sally Clark, the prosecution's theory was she had murdered her children, itself an extremely rare event.

Thanks mostly to Fisher's influence, these arguments have historically failed to win many converts to Bayesianism. But practical experience may now be starting to do what theory could not.

SUPPOSE THE WOMEN who received positive test results and a presumptive diagnosis of cancer in our example were tested again by having biopsies. We would see the majority of the initial results fail to repeat, a "crisis of replication" in cancer diagnoses. That's exactly what's happening in science today.

A follow-up study to Norenzayan's finding, with the same procedure and almost ten times as many participants, found no significant difference in God-belief between the two groups. In fact, the mean God-belief score in *The Thinker* group was slightly higher (62.78) than in the control group (58.82). But because the original study followed all the usual rules of research, the journal was justified in accepting the paper, which means the rules are wrong.

High-profile replication failures like Norenzayan's have led some scientists to call potentially all previous research into question. Large-scale projects have begun attempting to replicate the established results of various disciplines, and what they've found hasn't been pretty. It started in psychology. A collaborative project involving hundreds of researchers through the Center for Open Science found only 35 of 97 psychology studies (that is, 36 percent) successfully replicated. All had used significance testing.

Just a few of the other casualties of replication include:

-The study in 1988 by Strack, Martin, and Stepper on the "facial feedback hypothesis": when people are forced to smile, say by holding a pen between their teeth, it raises their feeling of happiness.

-The 1996 result of Bargh, Chen, and Burrows in "social priming," claiming, for example, when people are exposed to words related to aging, they adopt stereotypically elderly behavior.

-Harvard Business School professor Amy Cuddy's 2010 study of "power posing": the idea that adopting a powerful posture for a couple of minutes can change your life for the better by affecting your hormone levels and risk tolerances.

But the crisis won't stop there. Similar projects have shown the same problem in fields from economics to neuroscience to cancer biology. An analysis of preclinical cancer studies found that only 11 percent of results replicated; of 21 experiments in social science published in the journals *Science* and *Nature*, only 13 (62 percent) survived replication; in economics, a study of 18 frequently cited results found 11 (61 percent) that replicated; and an estimate for preclinical pharmacology trials is that only 50 percent of the positive results are reproducible, a situation that, given the immense size of the pharma industry, has been estimated to cost labs something like $28 billion per year in the United States alone.

We Bayesians have seen this coming for years. In 2005, John Ioannidis, now a professor at Stanford Medical School in the department of statistics, wrote an article titled "Why most published research findings are false."[3] He showed in a straightforward Bayesian argument that if a theory, such as an association between a gene and a disease, had a low prior probability, then even after passing a test for statistical significance it could still have a low probability of being true. He argued that this would be the norm in medicine, where a researcher can sift through many possible associations to find one that meets the threshold of significance merely by chance. Fourteen years later, we're seeing the same phenomenon in virtually all areas of science.

Now, a consensus is finally beginning to emerge: Something is wrong with science that's causing established results to fail. One proposed and long overdue remedy has been an overhaul of the use of statistics. In 2015, the journal *Basic and Applied Social Psychology* took the drastic measure of banning the use of significance testing in all its submissions, and in March 2019, an editorial in *Nature* co-signed by more than 800 authors argued for abolishing the use of statistical significance altogether. Similar proposals have been tried in the past, but every time the resistance has been beaten back and significance testing has remained the standard. Maybe this time the fear of having a career's worth of results exposed as irreproducible will provide scientists with the extra motivation they need.

The main reason scientists have historically been resistant to using Bayesian inference instead is that they are afraid of being accused of subjectivity. The prior probabilities required for Bayes' rule feel like an unseemly breach of scientific ethics. Where do these priors come from? How can we allow personal judgment to pollute our scientific inferences, instead of letting the data speak for itself?

But consider the supposedly "objective" probabilities in the Clark case. Meadow came up with his figure of 1 in 73 million by applying some adjustments to the observed incidence rate of SIDS (about 1 in 1,300) to account for what was known about the Clark family: They were nonsmokers with steady jobs and Sally was over the age of 26. How could he know he had adjusted for the all the right factors? Why not include the fact that she and her husband were both solicitors? The more specific information about the Clarks he included, the less available data he would have to go on, until his sample size was reduced to 1. He also assumed pairs of SIDS deaths in a family would be statistically independent, so their probabilities should get multiplied together, like the probability of a coin-flip coming up heads twice in a row. This assumption was roundly

criticized at the time, because the independence would be negated by any environmental or hereditary factor the children shared. But given the paucity of data on such rare events, wouldn't any correction for their dependency be somewhat subjective?

We all pay a price when the body of scientific research is polluted by false positives.

Drawing these lines, based on experience and expert judgment, is no less subjective than assigning a prior probability to a hypothesis such as Norenzayan's based on what we know about the world. Furthermore, it may not matter too much exactly what prior probability we use. Whether we consider the chance to be 1 in 1 thousand, million, or billion, the Bayesian analysis would tell us Norenzayan's results were not all that impressive, and we'd still be left extremely dubious. The point is that we have good reason to be skeptical, and we should follow the mantra of the mathematician (and Bayesian) Pierre-Simon Laplace, that extraordinary claims require extraordinary evidence. By ignoring the necessity of priors, significance testing opens the door to false positive results.

To a layperson, this debate about statistical methods may seem like an esoteric squabble, but the implications are much larger. We all have a stake in scientific truth. From small individual decisions about what foods to eat or what health risks to worry about, to public policies about education, healthcare, the environment, and more, we all pay a price when the body of scientific research is polluted by false positives. Eventually replication studies can sort the true science from the noise, but only at considerable cost. In the meantime we may be constantly upended by contradictory findings based only on statistical phantoms.

To address the crisis of replication, we must change the way we quantify and manage uncertainty in science. In its long history, probability has been misused to support bad reasoning in a wide variety of settings, from sports to medicine, economics, and the law. Most of these mistakes have, eventually, been corrected. Sally Clark was acquitted after spending three years in prison when it came to light that the pathologist who examined her second child had withheld key evidence from both the prosecution and the defense. But her appeal also exposed the flaws in Meadow's statistical argument. Two other women, Angela Cannings and Donna Anthony, who had been convicted in similar cases based on Meadow's testimony were released, and a third, Trupti Patel, on trial for the murder of her three infants, was acquitted. But the trauma of being wrongfully imprisoned for murdering her children continued to take its toll on Clark. A few years after being released she died of alcohol poisoning.

Medical students are now routinely taught the diagnostic importance of base incidence rates. Bayes' theorem helps them properly contextualize test results and avoid unnecessarily alarming patients who test positive for something rare. To leave out that final ingredient, the Bayesian prior probability, would be to commit a fallacy of the same species as the one in the Sally Clark case.

The crisis of replication has exposed the fact, which has been the shameful secret of statistics for decades now, that the same fallacy is at the heart of modern scientific practice.

AUBREY CLAYTON is a mathematician living in Boston. He teaches logic and philosophy of probability at the Harvard Extension School.

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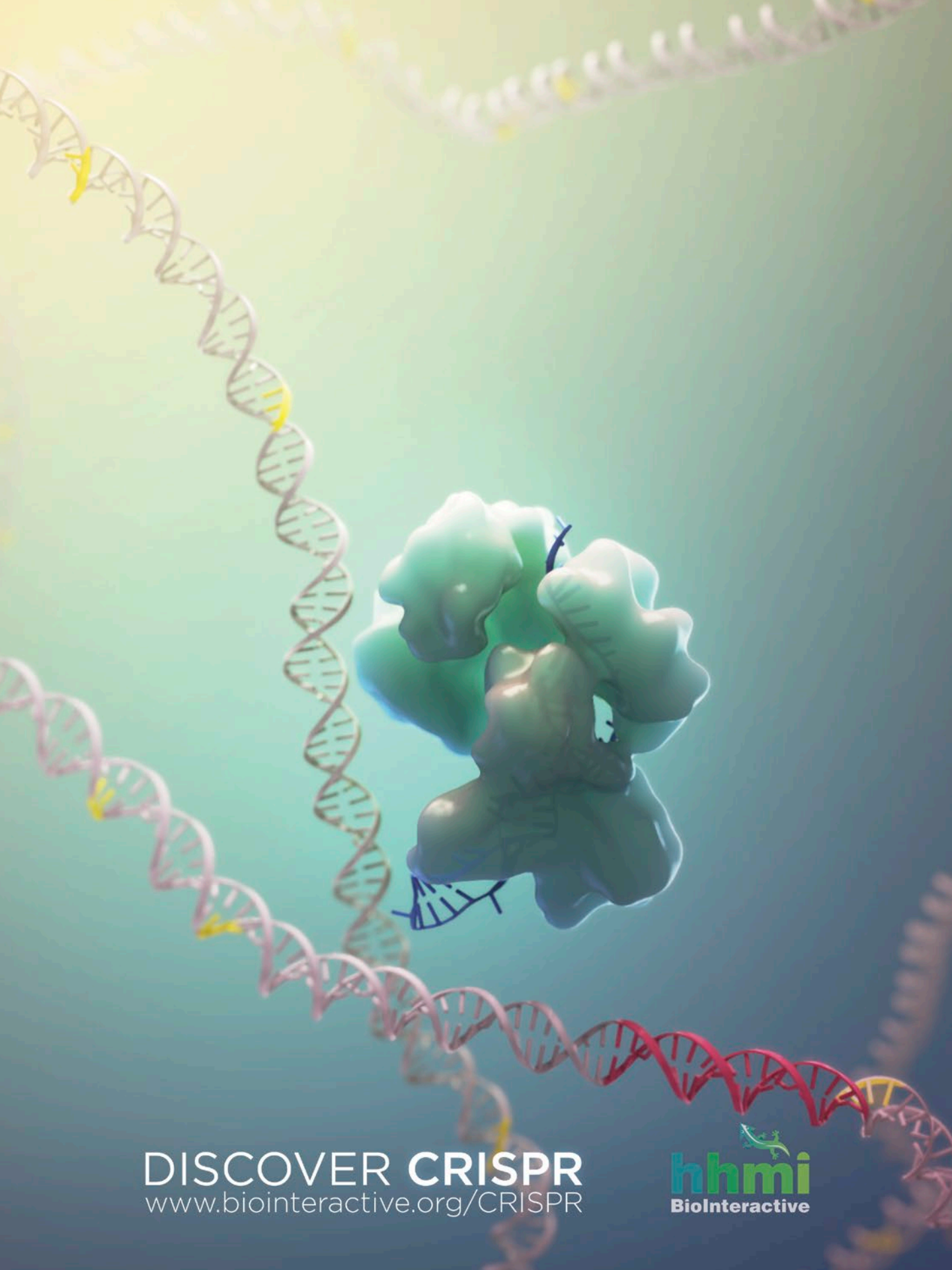
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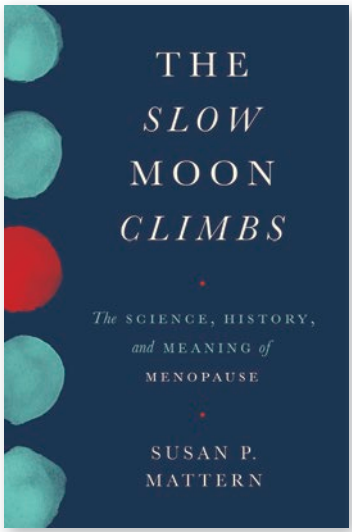

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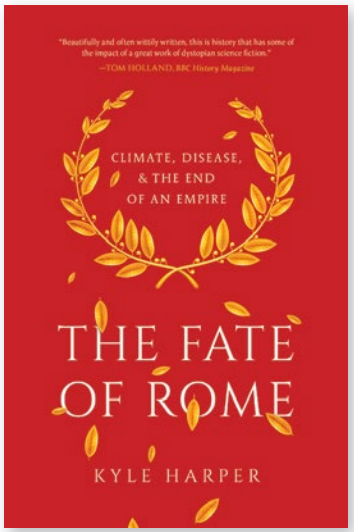

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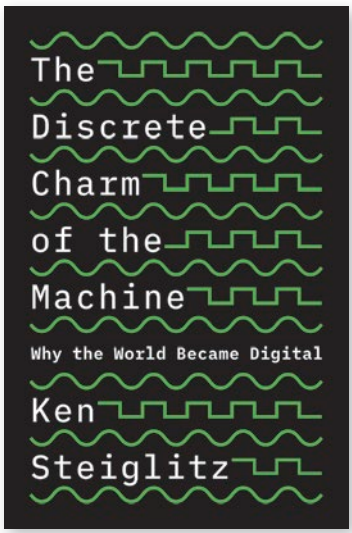

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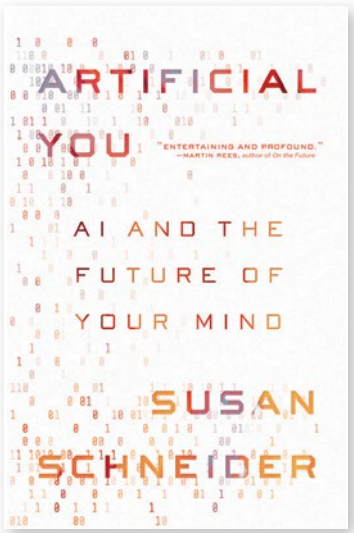

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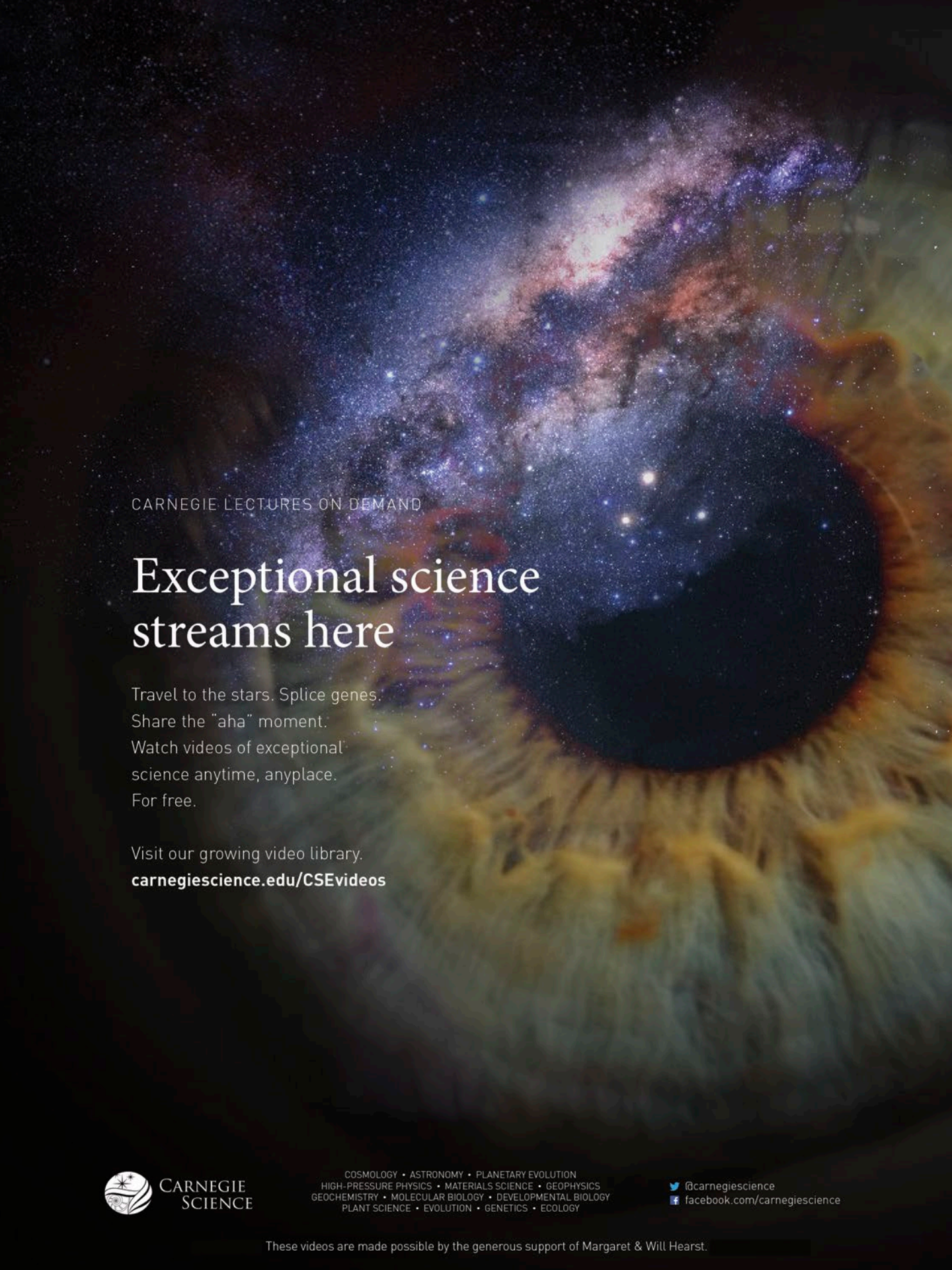
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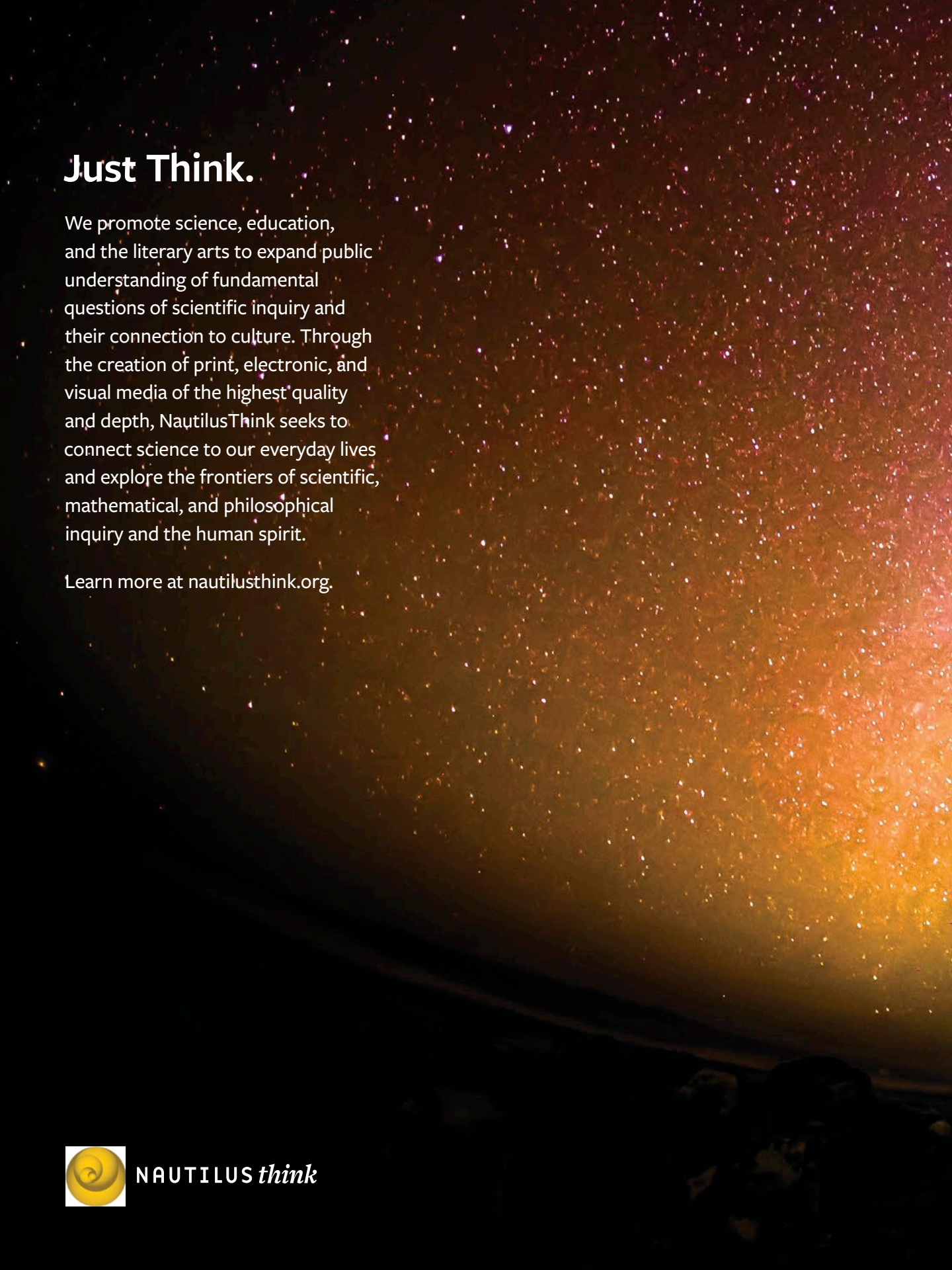

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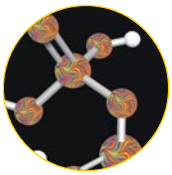

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Joseph Henrich

The evolutionary biologist on what gods say about people

INTERVIEW BY BRIAN GALLAGHER

GODS ARE LIKE PEOPLE

Different groups come to different beliefs about their gods. You find gods that care about what kind of foods you eat, who you have sex with, how you treat your neighbors, and these things help societies expand and grow. Some appeal to aspects of our psychology, which is why they stick around. Many gods in small-scale societies are like people, but with some extra, though limited, powers. People are sometimes punishing and so naturally the gods are, too. Intergroup competition essentially picked out and recombined the gods that helped societies succeed, whether by inducing cooperation or bravery in war. This meant, over time, gods became more powerful, knowing, and punishing as societies scaled up.

WORTH OF AN ANGRY GOD

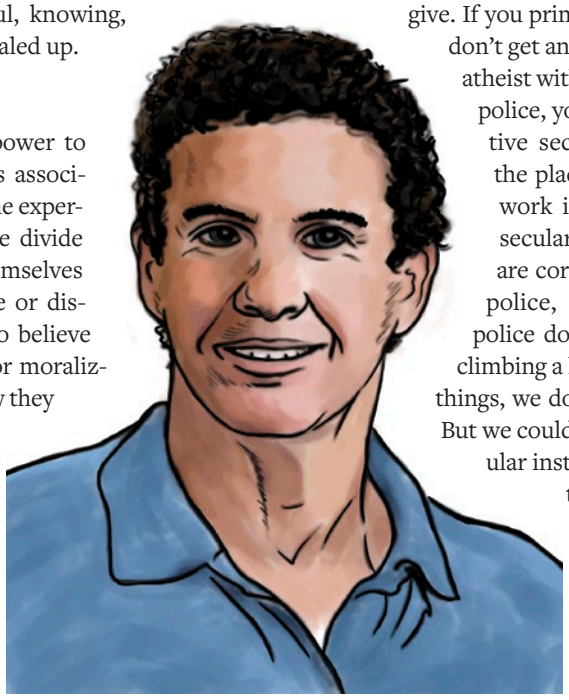
People's beliefs in a god's power to punish and monitor them is associated with sociality. We've done experiments where we had people divide sums of money between themselves or a member of their village or distant community. People who believe in gods that are punishing, or moralizing, are more equitable in how they allocate money between themselves and others.

WANING OF HELL

With the rise of strong secular institutions, representative governments, Western-style judicial processes, religion has become less important. While belief in a punishing god does a lot of the work of policing people, many Christians today believe in a loving God who's not much of a punisher. Belief in hell is on the decline. If you believe in a god that's loving, you're actually more likely to cheat. It's the belief in hell that did a lot of the work of keeping people in line.

IN PLACE OF GOD

Let's say we give people a chance to allocate money between themselves and a stranger. If you prime them with God unconsciously, and they're a religious person, you get a big increase in the amount they give. If you prime an atheist with God, you don't get any effect. But if you prime an atheist with courts and constables and police, you get an increase. So effective secular institutions can take the place of God. But this doesn't work in places without effective secular institutions. If the police are corrupt and nobody trusts the police, priming people with the police doesn't help. It could be like climbing a ladder. Once we build these things, we don't need religion anymore. But we could never have built these secular institutions without religion in the first place.



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