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BAD TEACHER

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THE MISUNDERSTOOD DONKEY

A tale of ecology



The Force

WALTER MURCH ON HISTORY'S SURGES OF CREATIVITY p.22

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A man with a beard and sunglasses, wearing a bright yellow jacket and white shorts, is crouching on a rocky, mountainous terrain. He has a wide, enthusiastic smile, showing his teeth. The background shows a clear sky and distant mountains.

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CONTACT

360 W 36th Street, 7S
New York, NY 10018

info@nautil.us

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Idea Journalism

BY KEVIN BERGER

AT *NAUTILUS*, WE ARE journalists of ideas. That's how I've described our mission since we launched in 2013. We investigate the fields of science and philosophy and return with stories that capture ideas that strike you like news and stay with you like literature.

When I stand back from our reporting and take in the range of insights and perspectives that we've gathered from thinkers, I marvel. For all the bad news in the world, and the distractions from it that the entertainment industry feeds us, there are scientists, writers, and philosophers whose intelligence enriches our minds and lifts our spirits. We give them the stage to provide you a refuge from the noise.

I offer the *Nautilus* issue in your hands. It begins with "Invisible Pyramid" by Academy Award-winning sound designer and editor Walter Murch, a Renaissance thinker. Murch has isolated periods in history that represent "fevers of achievement," such as the Great Pyramids, human flight, and his own field, cinema. What is the force that has spiked these surges of creativity and transformed societies and us?

The idea that Murch gives us to ponder is that our feverish inventions unraveled fixed concepts of space and time. That great unraveling freed us to dream previously unimaginable dreams, like making films like *Star Wars*, or decoding the human genome.

The big idea of our time is consciousness, and nobody has thought more deeply about it than Christof Koch, chief scientist at the Allen Institute for Brain Science in Seattle. In "What Counts as Consciousness," Koch offers an idea that's thrilling to ponder.

Consciousness, Koch says, "is the only thing that exists for itself. You are conscious. Tonight, you're going to go into a deep sleep at some point, and then

you're not conscious anymore; then you do not exist for yourself. Your body and your brain still have an existence for others—I can see your body there—but you don't exist for yourself. So only consciousness exists for itself; that's absolute existence. Everything else is derivative."

Our consciousness allows us to experience the world. What is the nature of experience? The thinkers to whom we give the spotlight in "What Science Forgets," assure us that experience is not strictly biological. Sometimes science treats the universe as something objectively measured, apart from ourselves.

That's so wrong. The "entire biosphere is implicated in your experience, you can't separate it out. There are no brains in vats," says astrophysicist Adam Frank. "Experience implicates everything, every aspect of life, the entire history of life."

One of the most consequential ideas today is that artificial intelligence is permeating our world, and we aren't sure what it's doing to us. In "When Kids Talk to Machines," writer and language scholar Julie Sedivy explains what AI is doing to children's education, and that it's being a bad teacher.

"From its beginnings, children's language learning is social, embedded in close relationships with people who are motivated to teach them," Sedivy writes. Kids' interactions with AI devices, by comparison, short-circuit their developing minds. Learning that is not interpersonal and social is not engagement with the whole world.

Ideas in this issue offer fresh perspectives on basketball, crying wolf, mud, comedy, and donkeys. I know that doesn't sound like a normal science magazine. "Only in *Nautilus*," though, is our favorite compliment of all.



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Hey. How did we wind up like this?

— Earth

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Short sharp looks at science

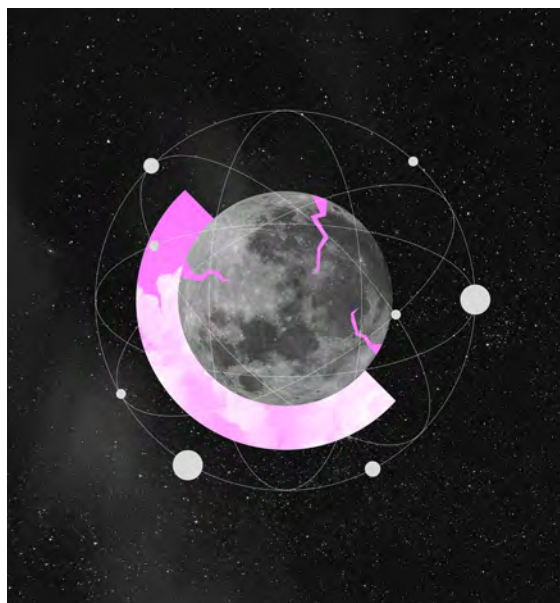
ASTRONOMY

A Cosmic Glitch in Gravity

EINSTEIN'S THEORY OF GRAVITY is a cornerstone of modern cosmology. It has been tested and proven correct over and over again and is supported by the discovery of countless cosmic phenomena: from the gravitational lensing detected by Arthur Eddington in 1919 and the anomalies observed in the orbit of Mercury, to galactic redshifts and gravitational waves. The theory of general relativity—to give Einstein's theory of gravity its proper name—has precisely predicted them all.

But astronomical observations near the “cosmological horizon”—where the farthest galaxies recede from us at nearly the speed of light—suggest gravity may act differently at the very largest scales. Now, some scientists propose Einstein's theory of gravity could be improved by adding a simple “footnote” to his equations, which amounts to a “cosmic glitch” in the scientific understanding of gravity.

Cosmologist Niayesh Afshordi is a senior author on a recent research paper, published in the *Journal of Cosmology and Astroparticle Physics*, that describes this “cosmic glitch” model as an extension to Einstein's gravitational theory. He and his colleagues suggest that their footnote would not only account for the observed large-scale discrepancies, but could also help ease other “tensions” in astronomy, where the predictions of the best theories don't agree with astronomical observations—including the expansion rate of the universe and the abundance of superclusters of galaxies.



“From an observational standpoint, there have been these anomalies in the data for well over a decade now,” says Afshordi, a professor of astrophysics at Canada's University of Waterloo and a researcher at the Perimeter Institute.

Scientists have made dozens of attempts over recent decades to modify Einsteinian gravity to better fit observations. One of these is the theory of “massive gravity” proposed by Claudia de Rham, a theoretical physicist at Imperial College London. Another is MOND, which applies modified Newtonian dynamics and was developed as an alternative to dark matter theories; in addition, there are several early dark energy



theories, which propose that the dark energy thought to drive the expansion of the universe was much stronger in the first 100,000 years after the Big Bang.

Unlike these other theories, which are driven by discrepancies in the data, the cosmic glitch model is derived from specific fundamental theoretical challenges to Einsteinian gravity that have been developed in recent decades, says Afshordi. These challenges include the Hořava-Lifshitz proposal—the idea that quantum gravity works differently at high energies—and the Einstein-aether framework, which reintroduces a dynamic form of the “aether” that Einstein aimed to eliminate.

“It’s a top-down approach,” says Afshordi of their cosmic glitch theory. It was only after they developed their theory to reconcile these theoretical issues that they decided to see if the theory fit the observational data from the Planck space telescope, which studied the cosmic microwave background between 2009 and 2013.

Afshordi says the results were remarkable.

The usual value for the gravitational constant in Einstein’s field equations—the core mathematical equations of general relativity—can accurately explain almost everything that’s been observed in the cosmos, he says. But field equations related to observations taken at the cosmological horizon seem to require a different value for the gravitational constant.

According to Afshordi’s colleague and co-author Robin Wen, a recent University of Waterloo graduate and now a doctoral student at the California Institute of Technology, the effect is that gravity becomes about 1 percent weaker over distances spanning billions of light-years.

The researchers found that applying their cosmic glitch model also reduces two important tensions in astronomy. The most notable is the famous Hubble tension: a discrepancy in values for the Hubble constant, a number that represents the expansion rate of the universe. Observations of cosmic microwave background radiation produce one value for the Hubble constant, while observations based on the “standard candle” supernovas in distant galaxies produce another value. The cosmic glitch model also reduces

The cosmic glitch model is derived from theoretical challenges to Einsteinian gravity.

a key component of the “clustering tension,” which measures the unexpected abundance of galaxy superclusters in the universe.

At the same time, however, the cosmic glitch model worsens the accuracy of predictions of baryonic acoustic oscillations, or BAOs—effectively “ripples” in the

average distances between galaxies, which seem to have been caused by pressure waves generated during the formation of the early universe. But the authors hope the BAO discrepancies can be improved with better modeling and observations.

Afshordi says that over the next several years, the CMB Stage 4 observatory and the Euclid Space Telescope are scheduled to collect new observations of the cosmic wave background and of billions of galaxies across 10 billion light-years, but with a precision four times greater than the ones that Afshordi and his colleagues used in their calculations.

If the cosmic glitch is there, that will be enough to reveal it, he says.

—Tom Metcalfe

ENVIRONMENT

How Melting Ice Has Altered Time-Keeping

C LIMATE CHANGE IS transforming our measurements of many things—summer temperatures, the level of the seas, the strength of hurricanes, for instance. But now, as polar ice caps melt with more regularity, it’s even messing with how we keep time.

According to a recent paper in *Nature*, that polar thaw has progressed to such an extent that it’s slowing the rotation of the planet. As the melt runs into the ocean, the extra water gathers around the Earth’s belly, fattening it a bit around the equator and reducing the



planet's angular velocity—or rate of spin. Think of an ice skater slowing her axel by extending her arms and you get the picture.

A slower rate of spin, in turn, alters the time it takes for the planet to rotate once—what we think of as a day—which means the rising and setting of the sun are not happening quite when we expect them to, putting a kink in the vast international network of infrastructure that tells us what time it is.

The problem is, even tiny deviations in time-keeping can wreak havoc with the systems we most depend on to orient us throughout our day. Things like financial markets, airline reservation systems, social media servers, and search engines all rely on hyper-accurate synchronizations of time across the globe, and when the timing is off, things can get pretty weird.

To smooth over recent discrepancies, by 2029, we'll need to add something called a negative leap second—a day where the clocks would go from 11:59 and 58 seconds directly to midnight, skipping 11:59:59—to allow our timekeeping devices to catch up with Earth, writes geophysicist Duncan Agnew of the Scripps Institute for Oceanography in the *Nature* paper.

It's something that has been anticipated—with no small amount of unease—for some time, Agnew says. One big problem is that we've never dealt with a negative leap second before. We've only ever added leap seconds—and the prospect of subtracting one has those responsible for keeping us on schedule nervous.

"A negative leap second is a serious business," says physicist Judah Levine, one of the world's primary timekeepers. For the past half century, Levine has worked at the National Institute for Standards and Technology in Boulder, Colorado, where he helps oversee NIST-F1—the cesium atomic clock that serves as the beating heart of time in the United States. It's one of about 450 cesium clocks from all over the globe that report data to the United Nations' International Telecommunications Union—which, in turn, disseminates the correct time to the rest of the planet via radio frequencies and the internet.

"There is a serious concern that the software to implement the negative leap second has bugs because it has never been tested," says Levin. "There are still problems with adding positive leap seconds, even though it has been done for 50 plus years."

The worst of these problems came on June 30, 2012, when the addition of a leap second broke some fundamental pillars of the web. As soon as the atomic clocks inserted a 61st second at midnight of that day, a timekeeping kernel in the open-source Linux operating system—which forms the backbone for much of the code on the internet as well as on Wall Street—popped. (A Linux subsystem called "hrtimer" couldn't reconcile the time differences, which sparked hyperactivity on servers running Linux, which then locked up the hardware of those machines.)

The cascading effects of that one hiccup caused Qantas Airlines' reservation system to crash, stranding passengers worldwide. Reddit, the enormous internet discussion platform, went dark. Java quit working. Mozilla internet browsers went a little haywire. Gawker, the once snarky pop-culture blog spot, dropped from view, as did Yelp, LinkedIn, and other monuments of the web's adolescent years. And rather than risk billions of dollars going astray, the New York Stock exchange and Nasdaq simply halted after-hours trading sessions to let the leap second pass.

BUT LET'S STEP BACK for a ... leap second, to explain why leap seconds came into use at all. Since 1972, the international community has precariously balanced two methods of keeping time. One method, based on the Earth's daily rotation, is as old as timekeeping itself, and relies on the position of the sun and other stars



in the sky. The other more precise method relies on the steady, unerring frequency of light emitted by the cesium atoms within atomic clocks, which supply the regularity so essential to the digital underpinnings of our lives.

The trouble is that, over time, the two different kinds of clocks—atomic and astronomic—tend to diverge. Astronomic time, called Universal Time, or UT1, has, until recently, tended to fall a few ticks behind atomic clock time, known as Universal Atomic Time, or TAI. While TAI runs at a steady 86,400 seconds a day, the planet itself is influenced by tides, the moon's gravity, and the currents of its molten liquid core, which aren't so exact or predictable.

The effect of these combined forces means that every few years we've had to bring TAI and UT1 back together by inserting a leap second—pausing the atomic clocks for a few beats to allow the astronomical clock to catch up. When the two clocks stray by nine-tenths of a second, the International Earth Rotation and Reference Systems Service in France schedules a leap second, which is added on December 31 or June 30 in whatever year it is needed. Once the two clocks are again in accord, they create what's called Coordinated Universal Time, or UTC—the time as we know it until the clocks, again, part ways.

This was all working *just fine*, said Agnew, until a few decades ago when activity in the Earth's molten liquid core caused the outer crust of the planet—where we live—to spin more rapidly. As the core spins faster, it gradually transfers some of its rotational momentum to the outer layers over long timescales. As a result, we recently began adding leap seconds less frequently than we used to. At first, they were needed almost annually—we added one 23 times between 1972 and 1999—but since the turn of the century, we have added only four, the last in 2016. Little by little, Agnew told me, it became clear that we could have to subtract one.

Originally, the dreaded negative leap second was predicted to fall in 2026. But data Agnew analyzed from satellites mapping Earth's gravity show that, since the 1990s, our planet has become less spherical and more oblong as ice in Antarctica and Greenland melts and

A negative leap second is a serious business.

moves toward the equator. This has subtly applied the brakes to the planet's rotation and delayed the negative leap second—and the screw-ups it could cause—by three years.

In the meantime, the Linux code blamed for the rippling mishaps in 2012 has been rewritten. Other computer giants that form the digital landscape like Google, Microsoft, and Meta now use their own proprietary systems to account for leap seconds. Meta, for instance, “smears” the 61st second across many hours so that Facebook, Instagram, and WhatsApp don't lose their bearings.

In Levine's view, big tech running separate code to grapple with leap seconds only creates more confusion. Their methods, he said, “are not consistent with the official definition [of time] and the different systems are not consistent with each other.” Further, Levine adds, how any of those corporations plan to handle subtracting, rather than adding, a second remains unknown. (Google, for instance, did not respond to my questions on the topic.)

“Having to deal with leap seconds drives me crazy,” says Levine. The rest of the world feels the same way. In November of 2022, timekeeping representatives from the world's governments gathered at the General Conference on Weights and Measures in Paris, and voted to abandon leap seconds from 2035 on.

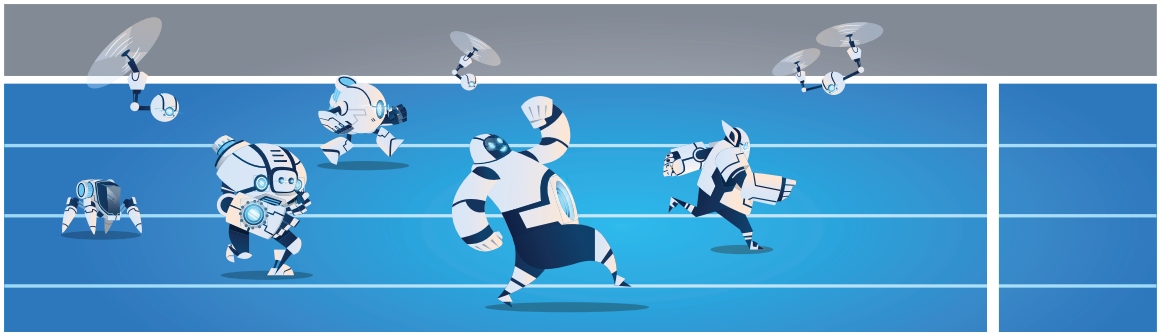
What will take its place thereafter—and keep the atomic and astronomical clocks aligned—is, Levine said, a big unknown. Levine himself has proposed something not unlike Meta's practice of smearing. In his method, an entire leap minute would be amortized over the course of a decade in an algorithmically guided sequence.

Getting everyone to agree on that is yet another headache as vexing as the leap second itself. “The political considerations are very often more important than the technical issue,” Levine tells me.

For now, the International Earth Rotation and Reference Systems Service has granted us a bit of a reprieve. According to an early 2024 bulletin, “NO leap second will be introduced at the end of June 2024.”

The announcement comes just in the nick of time.

—Charles Digges



TECHNOLOGY

Why Animals Run Faster than Robots

MORE THAN A DECADE AGO, a skinny-legged knee-less robot named Ranger completed an ultramarathon on foot. Donning a fetching red baseball cap with “Cornell” stitched on the front, and striding along at a leisurely pace, Ranger walked 40.5 miles, or 65 kilometers, on a single battery charge.

Ranger broke a record that day, walking farther than any robot before it—and that record remains unbeaten among robots. But Ranger’s pace was surprisingly pokey: It took 30 hours and 49 minutes to cover the distance, equivalent to a mile every 45 minutes. By comparison, the average human can walk at a speed of about 3 miles per hour, and marathon runners average a mile every 10 to 12 minutes.

It turns out that building robots that can walk and run as speedily and fluidly as humans and other animals, over both short and long distances, is extraordinarily complex. Even though the physical materials used in the construction of robots are often more resilient and powerful on a part-by-part comparison, the coordination of the parts seems to matter more for speed and agility. That’s where biological creatures have a leg up, according to new research led by Samuel Burden, robotics professor at the University of Washington.

To answer the question “Why do animals outrun robots?” Burden and his team decided to break down running into its major component systems and then compare the biological version to the engineered. They

took this approach rather than compare specific robots to individual animal species because “we didn’t want to tear down any particular robot,” says Burden. This way, they reasoned, the comparison would also be at its purest, since no robot or animal is designed exclusively for running, per se.

The component systems the research team considered included power, frame (for animals both vertebrate skeletons and the exoskeletons of insects were considered), actuation (how running is put into action, which is mostly through muscle in biological creatures and motors in robots), sensing (how the ground looks and feels underfoot), and control, each of which directly affect a runner’s performance.

Ranger, for example, shines in the power category because among machines it has an impressive record of converting the stored energy in its battery into steps over considerable distance and time. It lags behind, though, when it comes to sensing and control. Ranger walked the ultramarathon across a perfectly manicured athletics track, where even the slightest anomaly in the terrain would have tripped up its progress.

The robots that perform best in the control category are those equipped with neuromorphic silicon chips, designed to mimic the wiring of an animal brain, the researchers found. Instead of using a binary system of zeros and ones to transmit digitized information, neuromorphic chips use analog signals spiked along an artificial neural network. The network has junctions that mirror the design of synapses in animal brains. The



When each subsystem was considered in isolation, robots, with very few exceptions, outperformed animals.

Tianjic chip, for example, which simulates the architecture of 40,000 neurons wired together, is used to control a robotic bicycle, which expertly maneuvers around obstacles. In principle it could be used to outfit a robot runner, too.

Paradoxically, the researchers' analysis showed that when each subsystem was considered in isolation, robots, with very few exceptions, outperformed animals. Bones and biological exoskeletons are weaker than the steel, aluminum, and carbon fiber materials that tend to make up a robot's frame, and even though fat is a richer source of power than the best battery, a robot powered by gasoline would always outlast an animal given unconstrained access to a refueling station. The control category was an exception, as animal brains predictably outclass silicon chips on the sheer magnitude of neurons they contain. But it's not clear that a higher number of neurons alone can dictate a robot or animals' agility in movement.

So why, on the whole, haven't we been able to design robots that run as well as, or better than, animals yet? It's not an idle, purely philosophical question: "There are many circumstances where it would be very valuable if our robots were better, comparable, ideally exceeding the performance [of animals]," says Burden. "For example, we could make better assistive devices like exoskeletons or prosthetics."

According to Burden, engineers have spent too much time focusing on the component parts of their robots, missing the emergent properties of the whole. "Rather than focusing on the latest, newest, fanciest, most expensive component that's going to make my robot better, maybe we could take a step back and think more carefully about the parts we have, and do better with those," says Burden. "One way to interpret that is we need new metrics that are quantifying either whole system or more tightly integrated subsystems."

As Burden and his colleagues note in their paper, animals have lived through up to 10 million times more

generations than robots. In terms of individual experience, animals also tend to have longer lifespans than robots and may take roughly 10,000 steps a day over the decades that they live. They have had a lot more time to figure out how to run and to walk.

So, evolution may have given humans a head start, but in Burden's view robotics stands a chance at catching up. "It's not an undirected search, the way that it is with evolution" he says. Engineers are masters of optimization; they simply haven't figured out exactly which properties they need to optimize, yet.

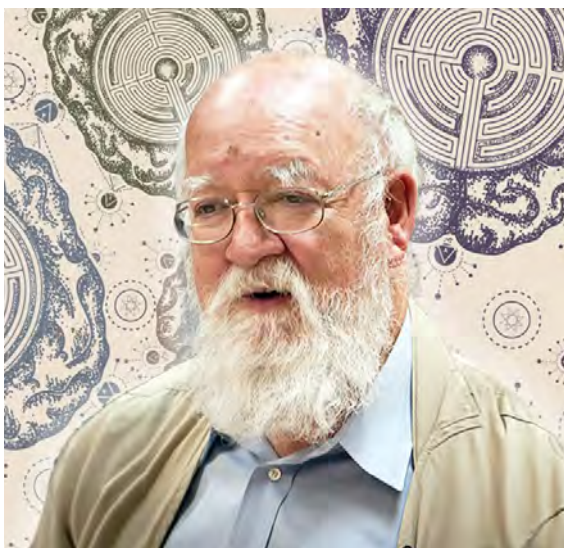
—Elena Kazamia

PHILOSOPHY

4 Brilliant Insights from Daniel Dennett

DANIEL DENNETT, WHO DIED IN APRIL at the age of 82, was a towering figure in the philosophy of mind. Known for his staunch physicalist stance, he argued that minds, like bodies, are the product of evolution. He believed that we are, in a sense, machines—but astoundingly complex ones, the result of millions of years of natural selection.

Dennett wrote more than a dozen books, some of them aimed at a scholarly audience but many of them directed squarely at the inquisitive non-specialist—including bestsellers like *Consciousness Explained*, *Breaking the Spell*, and *Darwin's Dangerous Idea*. Reading his works, one gets the impression of a mind jammed to the rafters with ideas. As Richard Dawkins put it in a blurb for Dennett's last book, a memoir titled *I've Been*



Thinking: “How unfair for one man to be blessed with such a torrent of stimulating thoughts.”

Dennett spent decades puzzling over the existence of minds. How does non-thinking matter arrange itself into matter that *can* think, and even ponder its own existence? A long-time academic nemesis of Dennett’s, the philosopher David Chalmers, dubbed this the “hard problem” of consciousness. But Dennett felt this label needlessly turned a series of potentially solvable problems into one giant unsolvable one: He was sure the so-called hard problem would evaporate once the various lesser (but still difficult) problems of understanding the brain’s mechanics were figured out.

Because he viewed brains as miracle-free mechanisms, he saw no barrier to machine consciousness, at least in principle. Yet he had no fear of *Terminator*-style AI doomsday scenarios, either. (“The whole singularity stuff, that’s preposterous,” he once told an interviewer for *The Guardian*. “It distracts us from much more pressing problems.”)

As keen as the workings of his mind may have been, Dennett was among the least pretentious of scholars. As one journalist noted, he dressed “like a Maine fisherman”; for many years, he and his wife, Susan, spent their summers in a farmhouse a five-hour drive north of Boston. His passions extended beyond science and philosophy: He mastered at least five musical instruments—for

Free will is not an illusion we should want to dismantle or erase; it’s where we live, and we couldn’t live the way we do without it.

a time he earned money as a jazz pianist—and, in spite of his avowed atheism, sang Christian hymns like “O Hearken Ye” like a practiced choirboy.

To give a sense of the breadth and depth of Dennett’s thinking, we have compiled here four snippets from his writings.

FREE WILL IS A FANTASY, BUT A WELCOME ONE

The traditional view of free will, as a personal power somehow isolated from physical causation, is both incoherent and unnecessary as a grounds for moral responsibility and meaning. The scientists and philosophers who declare free will a fiction or illusion are right; it is part of the user-illusion of the manifest image. That puts it in the same category with colors, opportunities, dollars, promises, and love (to take a few valuable examples from a large set of affordances). If free will is an illusion then so are they, and for the same reason. This is not an illusion we should want to dismantle or erase; it’s where we live, and we couldn’t live the way we do without it. But when these scientists and philosophers go on to claim that their “discovery” of this (benign) illusion has important implications for the law, for whether or not we are responsible for our actions and creations, their arguments evaporate.

—*From Bacteria to Bach and Back* (2017)

CONSCIOUSNESS RUNS ON MULTIPLE PARALLEL TRACKS AT ONCE

According to the Multiple Drafts model [of consciousness], all varieties of perception—indeed, all varieties of thought or mental activity—are accomplished in the brain by parallel, multitrack processes of interpretation and elaboration of sensory inputs. Information entering the nervous system is under continuous “editorial revision.” For instance, since your head moves a bit and



your eyes move a lot, the images on your retinas swim about constantly, rather like the images of home movies taken by people who can't keep the camera from jiggling. But that is not how it seems to us. People are often surprised to learn that under normal conditions, their eyes dart about in rapid saccades, about five quick fixations a second, and that this motion, like the motion of their heads, is edited out early in the processing from eyeball to ... consciousness.

—*Consciousness Explained* (1991)

CULTURAL EVOLUTION CAN MIMIC BIOLOGICAL EVOLUTION

The concept of cultural replicators—items that are copied over and over—has been given a name by Richard Dawkins, who proposed [in his 1976 book *The Selfish Gene*] to call them memes, a term that has recently been the focus of controversy. For the moment, I want to make a point that should be uncontroversial: Cultural transmission can *sometimes* mimic genetic transmission, permitting competing variants to be copied at different rates, resulting in gradual revisions in features of those cultural items, and *these revisions have no deliberate, fore-sighted authors*. The most obvious, and well-researched, examples are natural languages. The Romance languages—French, Italian, Spanish, Portuguese, and a few other variants—all descend from Latin, preserving many of the basic features while revising others. Are these revisions *adaptations*? That is,

are they in any sense *improvements* over their Latin ancestors in their environments? There is much to be said on this topic, and the “obvious” points tend to be simplistic and wrong, but at least this much is clear: Once a shift starts to emerge in one locality, it generally behooves local people to go along with it, if they want to be understood.

—*Breaking the Spell* (2006)

DARWINIAN EVOLUTION HAS EXTRAORDINARY EXPLANATORY POWER

Let me lay my cards on the table. If I were to give an award for the single best idea anyone has ever had, I'd give it to Darwin, ahead of Newton and Einstein and everyone else. In a single stroke, the idea of evolution by natural selection unifies the realm of life, meaning, and purpose with the realm of space and time, cause and effect, mechanism and physical law. But it is not just a wonderful scientific idea. It is a dangerous idea. My admiration for Darwin's magnificent idea is unbounded, but I, too, cherish many of the ideas and ideals that it seems to challenge, and want to protect them. ... The only good way to do this—the only way that has a chance in the long run—is to cut through the smokescreens and look at the idea as unflinchingly, as dispassionately, as possible.

—*Darwin's Dangerous Idea* (1995)

—Dan Falk

GEOSCIENCE

We Came from Lowly Mud

WE LAND-DWELLERS TEND to take for granted the continents upon which we live out our days and nights. But Earth's continents are in fact a planetary oddity. No other planet in our solar system—or outside of it, as far as we know—hosts large land masses like Africa or Australia, separated from one another by vast oceans.

Although other rocky planets and moons in our solar system have topographic highs and lows, the continents

on Earth are not simply higher in elevation than the ocean basins; they are made of something entirely different: granite.

But how exactly these granite continents formed—and survived—has remained a longstanding mystery.

A recent paper in *Nature* suggests it was only after these land masses rose out of the sea, and not before, that they became the strong and durable continents we know today. The authors propose that weathering from rain and wind concentrated radioactive elements



in the emergent rock, producing sufficient heat to transform it into granite. The counter-intuitive finding tells us that the atmosphere and hydrosphere shaped the Earth's continents and provides insight into how habitable Earth-like planets might evolve elsewhere in the universe.

As silica-rich magmas melted out of the mantle, these would have accumulated into thicker bodies, buoyant proto-continents that began to stand higher than the global ocean, argue co-authors Jesse Reimink and Andrew Smye, both professors of geoscience at Penn State University. One might imagine that exposure to the destructive forces of weathering and erosion would work against continental growth—that when the continents came up for air, they would have sown the seeds of their own destruction.

But, instead, Reimink and Smye suggest that exposure-related breakdown of rock was in fact the key to a burst of granite production that solidified “cratons” into the durable cores of the modern continents. These cratons have been compared to the keel of a boat—they keep the continents floating at or near sea level across vast timescales.

While erosion flattens topography, it tends to redistribute, rather than remove, mass from the continents. Most sediments accumulate either on the submerged flanks of land masses—the continental shelves—or in low-lying inland basins. As sediments move from their rocky sources to ultimate sites of deposition—a process that is mostly driven by rivers—they interact with water and atmospheric carbon dioxide, which changes their chemistry. Easily dissolved elements like sodium

are carried away in solution, leaving a residue of quartz and clay minerals, which are then deposited as sandstones and shales—the latter also known, less elegantly, as mudstones.

Although they don't tend to form the dramatic landscapes that sandstones often do—think of the rock arches and slot canyons of the American Southwest—mudstones are more abundant, representing about 70 percent of all sedimentary rocks by volume. Mudstones also tend to contain high concentrations of insoluble trace elements, most notably uranium and thorium, both of which are radioactive and therefore generate heat.

Reimink and Smye wondered how the “invention” of large amounts of heat-producing shale or mudstone via weathering might have altered the crust.

Between about 3 and 2.5 billion years ago, a worldwide episode of crustal melting occurred called the “Neoarchean granite bloom.” During this time, large volumes of granites were thrust into the nascent continental masses, “gluing” them together into sturdy cratons.

Previous hypotheses for the cause of the granite “bloom” had invoked heat rising from the mantle, but even the young continents would have been thick enough to insulate themselves against heat emanating from below. Reimink and Smye suggest, instead, that “hot” mudstones created by weathering became buried or tectonically folded into the early continental crust, and then heated it from *within*.

The authors present the results of computer models showing that for plausible volumes of shale and higher amounts of uranium and thorium in Archean time, radioactive decay could have heated existing crustal rocks—both granites and sediments—to their melting temperatures, producing large volumes of new granite and solidifying the cratons. That is, the shales were hot enough to “cook” themselves and the surrounding rocks to the point of melting, and those magmas, long since cooled, form the nearly indestructible crust beneath our feet.

In other words, we may owe our land-dwelling existence to lowly mud.

It's a reminder not to take granite—or mud—for granted.

—Marcia Bjornerud

ZOOLOGY

A Model Toadlet

M **EASURING JUST A FEW MILLIMETERS** long, the pumpkin toadlet is diminutive in size but flamboyant in coloration. This tiny neon creature, which lives on Brazil's southeast coast, has become a symbol of conservation and protection for the Atlantic Forest, a rainforest that sits just 50 kilometers from Brazil's largest city, São Paulo.

Recently, a team of researchers from Brazil and the California Academy of Sciences traveled to Serra do Mar State Park, to begin marking, swabbing, and collecting DNA from a population of pumpkin toadlets. The researchers want to understand how the frogs cope with chytrid fungus, considered by some to be the most lethal wildlife pathogen in recorded history.

The water-borne fungus, which infects the skin of amphibians, has devastated many frog populations around the world. According to some estimates, chytrid disease has led to extinctions in up to 90 amphibian species and declines in more than 500, wreaking havoc on entire ecosystems along the way.

Together the Brazilian and American scientists studying the pumpkin toadlet in the Atlantic Forest have identified individuals of the species that seem to be resistant to the fungus—they recover from it all on their own. They hope that learning more about these special little frogs and what allows them to hold out could help us protect frogs around the world against future outbreaks.

— Katie Garrett

This story originally appeared in bioGraphic, an independent magazine about nature and regeneration powered by the California Academy of Sciences.



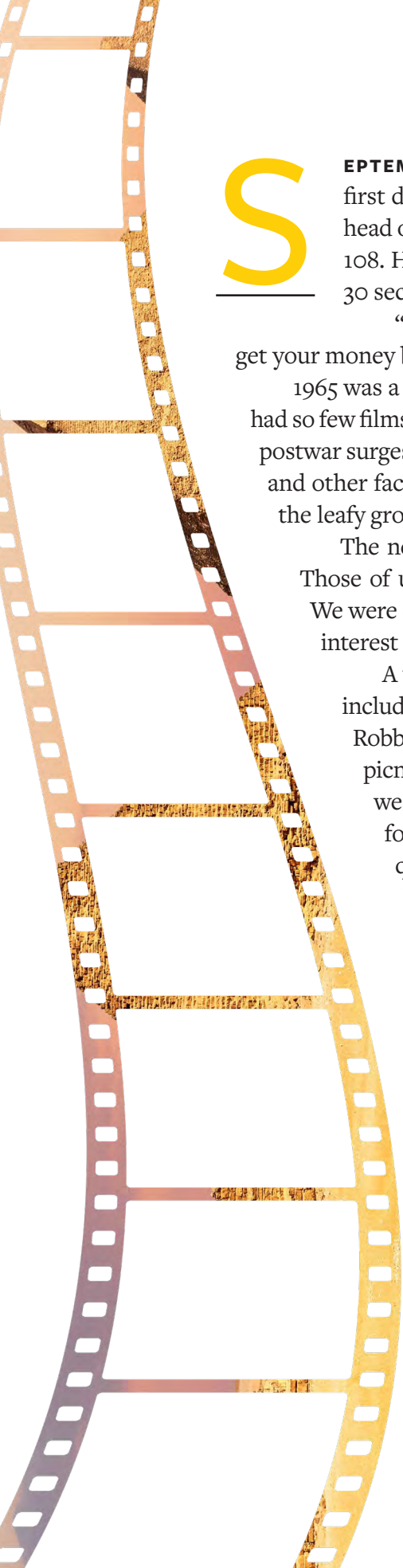


Invisible Pyramid

History is made by mysterious surges of creativity. Where are they taking us?

BY WALTER MURCH





SEPTEMBER 1965. **EIGHTY EAGER** young faces are assembled for the first day of orientation at USC School of Cinema. Gene Peterson, head of the camera department, walks onstage in Projection Room 108. His cornflower blue eyes scan the crowd for an unendurable 30 seconds of silence.

“Here’s my advice,” he says to us. “Get out now. You can still get your money back.”

1965 was a low tidemark year in Hollywood—never before (and since) had so few films been produced. The 20-year slide had begun in 1946 with the postwar surges of TV, cars, and suburbs. It was one of the reasons Peterson and other faculty at USC Cinema had become teachers, seeking cover in the leafy groves of academe.

The next day, a third of the class had opted for greener pastures. Those of us who remained did so because, well, that is the question. We were double the previous year’s admission of 40. Why the surge of interest in film at a time when the business was shrinking?

A year later, the faculty identified eight of us as troublemakers, including George Lucas, John Milius, Caleb Deschanel, Matthew Robbins, Randall Kleiser, and me. We were called to sit around a picnic table in the central corral of the cinema department, where we were harangued by our professors for our unwillingness to follow the school rules: No movie should be made more than a quarter mile from the school; only black and white film should be used; no more than 55 minutes of 16mm film should be shot. We were accused of breaking into the mixing theater at 2 a.m. to re-record our films, of not returning equipment on time, of sneaking into the equipment stock room with forged keys to get our hands on precious cameras and sound recorders. All of this was true.

This dressing-down was duplicated across town at UCLA’s School of Theater, Film, and Television, where Francis Ford Coppola and Carroll Ballard had been students a few years earlier; or NYU Film School in New York where Martin Scorsese was a student contemporaneous with us; or Long Beach State where Steven Spielberg would soon be enrolling. None of us had any prior connection to Hollywood.



Once we left school, all of us encountered different forms of The Wall—the barricade that says, “Go away.” The studios were surrounded by literal cement walls, usually about 15 feet high, which broadcast that message clearly. But there were other, invisible walls that we encountered, like the impenetrable Don’t-call-us-we’ll-call-you force field. Ultimately, we film students of the 1960s found our way through, under, or over The Wall and became responsible for films such as *Patton*, *The Godfather* trilogy, *American Graffiti*, *The Conversation*, *Jaws*, *Star Wars*, *Close Encounters of the Third Kind*, *Grease*, *Taxi Driver*, *The Black Stallion*, *Apocalypse Now*, *Raging Bull*, *Raiders of the Lost Ark*, *ET*, and many others. Along with Oscars and, for a few of us—present company excepted—great wealth and fame.

RICHARD BEGGS

MEETING IN THE JUNGLE Director Francis Ford Coppola and Walter Murch (right) in discussion on a set of *Apocalypse Now*. Murch was the film’s sound designer, for which he won an Academy Award.

These inventions and revolutions unraveled space and time.

In 2004, nearly 40 years after our student days, I was walking along Kearny Street in San Francisco and came across Francis sitting outside his Café Zoetrope at one of the little tables, trying to write. Since the '60s, I had worked with Francis as a sound designer and film editor, including on all three *Godfather* films, *The Conversation*, and *Apocalypse Now*. I sat down with him, and we chatted. I was about to start editing Sam Mendes's *Jarhead*, and Francis was struggling with a draft of *Youth Without Youth*, an original screenplay. The blank sheet of paper stared back at him defiantly. "To have come all this way and find myself in exactly the same predicament. What do I want to say and how do I want to say it?"

A tourist bus in the guise of a cable car drove past with its loudspeaker blaring, "Francis Coppola, creator of *The Godfather* series ..." Francis waved amiably at the tourists, who—startled—waved back.

Not long after, I thought about the sudden surge of interest in cinema that so perplexed Peterson in 1965. Looking through the opposite, wide end of the telescope, it is possible that no matter what agency we filmmakers thought we had, we were being pushed along by an invisible cultural wave-force that has only grown more massive over the decades. The United States had three film schools in 1965. There are now 750.

AWE OF THE PYRAMIDS

Is history made by individuals, or are individuals made by history—carried along by waves of impersonal forces? Near-contemporaries Thomas Carlyle and Karl Marx, in the 1840s and '50s, offered the two poles of this conundrum. Carlyle felt that "the history of the world is simply the biography of great men," while Marx professed the irresistible and impersonal forces of evolving class conflict.

Whatever the answer—and it must include some mixture of both—history is streaked with periodic fevers of achievement, which grip and shake entire societies for centuries at a time, and then—as suddenly as they had been gripped—release them transformed.

The frenzy of pyramid building in Egypt—the classic age of the massive stone structures at Giza and Dashur—lasted not quite 200 years, from 2675 to 2500 B.C. During that span of seven generations, seven pyramids were built, taking 20 to 30 years each, directly involving 30,000 workers at the peak months of construction, and hundreds of thousands of secondary supports, at a time when the total population of Egypt was just over 1 million. Twenty million tons of limestone and granite were quarried and transported—the granite floated down the Nile on barges from Aswan, 700 kilometers to the south—using only human muscle

power and copper tools. Contrary to stories spun by Herodotus and amplified in the 19th century, no slaves were involved—most workers were farmers idled during the four-month flood season from mid-June to mid-October. They were paid, housed, and fed, and the graffiti they left attest to their enthusiasm.

The pyramids were the first large-scale, all-stone constructions in history, raised to then-unimaginable heights of almost 500 feet, and everyone in Egypt must have been aware and in awe of what they were creating. The Nile Valley at that time was one of the only places in the world with an agricultural surplus capable of supporting such an effort. It's arguable that the collective accomplishment of pyramid construction, along with the innovative social organization necessary, was the forge that finally and firmly cemented the two kingdoms of Egypt into one of the first, and longest-lasting, nation-states in history.

Visitors to Giza feel a fragment of this awe today, which my wife Aggie and I were fortunate to experience in 1980 when I was writing a screenplay about archaeology. The Great Pyramid is, objectively, “just” a pile of stones, but it is steeper than any pile you would ever see in the natural world. It inclines at 52 degrees, 7 degrees steeper than the maximum angle of repose. No simple pile of aggregate—stone, sand, or gravel—is stable at greater than 45 degrees. Their stability was due to their precise construction and internal buttressing: interior walls of stones leaning against each other at 75 degrees.

Structurally speaking, the pyramids are already collapsed, so to speak, and have nowhere farther to go. In that engineering sense, the pyramids are supernatural, and this is something you feel, viscerally, standing in front of them. They are magnificent and unsettling at the same time. If we feel this today, how much stronger

must that have been 4,600 years ago when there was no comparable human achievement anywhere on Earth?

The same feelings arise again in the frenzy of 350 years of cathedral-building in Europe, from the middle of the 12th century to the 16th century. Well over 100 huge gothic cathedrals were built for the bishops of Europe, along with many thousands of churches. The cathedrals boasted immense interior spaces filled with light streaming through magnificent stained-glass windows, and the seemingly unsupported pointed arches floated high above the heads of the congregation. One of these cathedrals, at Lincoln in England, exceeded the Great Pyramid in height by about 46 feet—after almost 4,000 years it was the first time the Pyramid's height had been surpassed.

Like the construction of the pyramids, these three centuries of cathedral-building were instrumental in forging a unity out of the multiplicity of Europe, with master-architects and craftsmen ceaselessly crisscrossing borders to spread their cultural and engineering skill set from country to country. Estimates are that around 20 percent of all economic activity during this period was dedicated to the construction of cathedrals and churches throughout Europe.

PYRAMID POWER

The frenzy of pyramid building in Egypt lasted not quite 200 years, from 2675 to 2500 B.C. It represents one of history's mysterious fevers of achievement.



The cinematic cut is where the chisel of the splice cleaves the stone of time.

These examples (out of hundreds from world history) reveal how a society can be suddenly rocked by breakthrough developments, which flow through the entire population in a dozen generations or so, flooding society with their transformative effects, before they dissipate, sometimes suddenly, leaving a reimagined, transformed society in their wake.

Are we embroiled in one of these waves now, at the beginning of the 21st century? Have we been for some time?

FILM TAKES FLIGHT

When I was 15, I read *The Immense Journey* by Loren Eiseley, who has had a great influence on my thinking ever since. “How Flowers Changed the World,” one of the essays in the book, taught me that evolution often has the uncanny ability to “Houdini” itself out of seemingly intractable puzzles, turning the attacks of animals on plants into actions that spread pollen and seeds in directed vectors. The plants have co-opted their enemies, and no longer needed to rely on the mindless whims of wind and water for propagation.

In 1970, Eiseley wrote *The Invisible Pyramid*. It was his attempt to deal with the phenomenological effects

of powered air and space travel over his lifetime. How had this epochal achievement transformed society, expanding not only our sense of reality but also the limits of what was possible? In Eiseley’s opinion, it was as transformational as the construction of the Egyptian pyramids, but a transformation so pervasive and universal as to be invisible—not localizable to a single set of spatial coordinates.

Eiseley was born in 1907, four years after the Wright brothers lifted off at Kitty Hawk in 1903. He saw Halley’s comet when he was 3 and lived to see men on the moon in 1969, but not Halley’s return in 1986.

The year of Kitty Hawk was also, serendipitously, the year of Edwin Porter’s *The Great Train Robbery*—the first massively popular film to use editing to tell a complex story. And edited film, along with powered flight, are the two miraculous inventions whose reach and scope would come to define the 20th century in all its glory and horror.

Thanks to film editing, long and complex films like D.W. Griffith’s *The Birth of a Nation* could be planned, broken down into individual shots and scenes, and photographed in the most efficient order. They could be reknit into a convincing three-dimensional mosaic—two

dimensions of space and one of time—to represent, in symphonic or novelistic terms, the full breadth of the human comedy or tragedy. Editing freed cinema from the binding gravitational pull of the single shot, and allowed it to take off, in both a creative and a logistical sense. It is a poetic coincidence that those two symbols of the previous century, edited film and powered flight, have almost simultaneous birthdays.

Yet film and flight are perhaps part of an even larger wave, one of those world-encompassing eruptions of creativity, which began suddenly in the 1830s and is ongoing 200 years later.

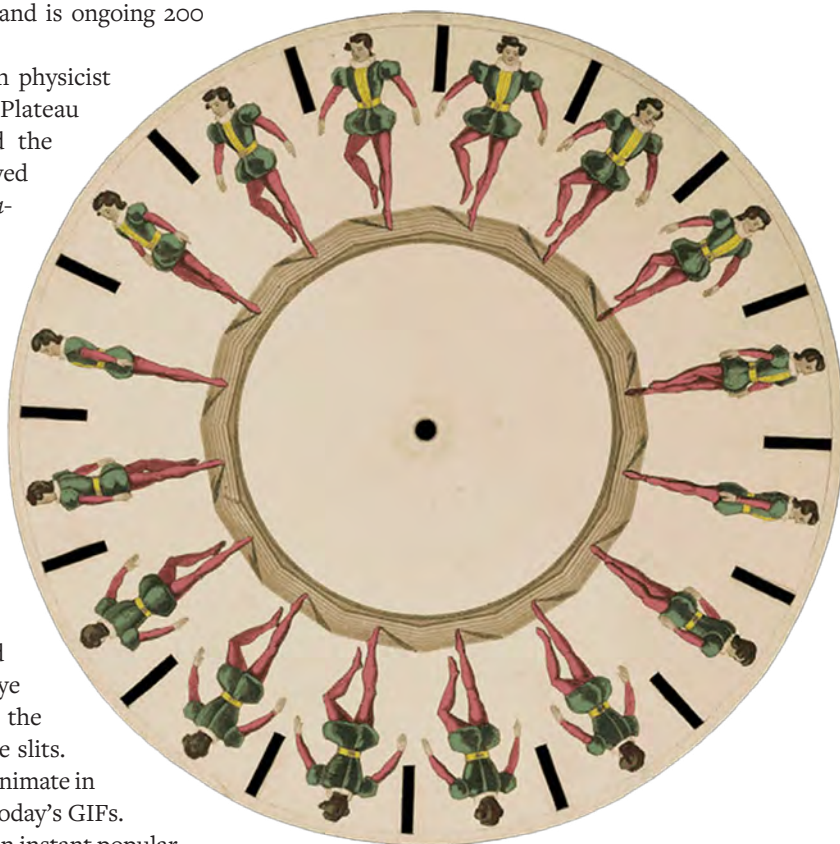
It was in 1833 that Belgian physicist and mathematician Joseph Plateau invented a device he called the phenakistoscope, a word derived from the Greek words *phēnā-kistes*, meaning imposter, and *skopein*, meaning to look.

Plateau's invention was a rotating disk with slits around its circumference like the hours of a clock and a series of drawings on the opposite side from the viewer—usually of a human being in action (walking, jumping)—each drawing lining up with one of the slits.

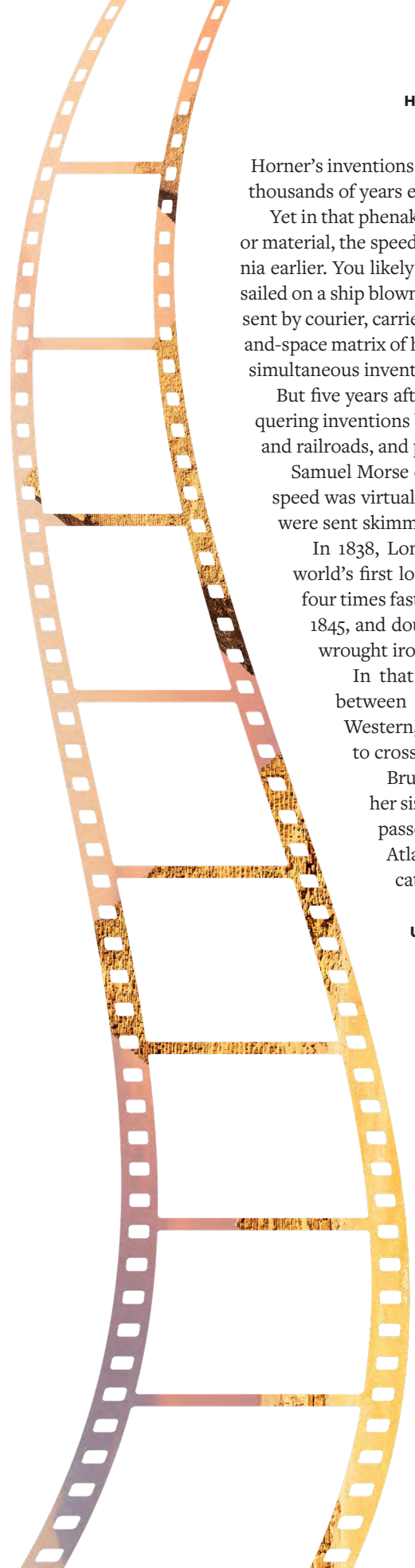
To operate it, you would hold the disk between your eye and a mirror and then spin the disk while looking through the slits. Amazingly, the images would animate in a repeating loop, exactly like today's GIFs.

The phenakistoscope was an instant popular success, releasing a surge of dammed-up creativity, thanks to the fabulous nature of the drawings created for it—rats or snakes surging from the center of the disc to the circumference!—as well as an improved technology, the zoetrope, invented in 1834 by British mathematician William Horner.

Horner's invention was a rotating drum with slits and a strip of drawings on the inside, and did not require a mirror to view the animation. You could spin the drum in one direction and young girls would be transformed into old crones; spinning in the other direction, crones turned back into young girls. Both Plateau's and



THE FIRST GIF The phenakistoscope, invented in 1833, was the first animation device. You held its disk up to a mirror and spun it while looking through its slits. Images, like a pirouetting man, animated in a repeated loop



Horner's inventions were so simple in construction that they could have been invented thousands of years earlier by the ancient Egyptians.

Yet in that phenakistoscopic year, 1833, if you wanted to move yourself, information, or material, the speeds available to you were roughly the same as they were four millennia earlier. You likely walked, ran, galloped on a horse, rode in a horse-drawn carriage, sailed on a ship blown by the wind or rowed by ranks of galley slaves. Messages could be sent by courier, carrier pigeon, semaphore, mirrors, smoke signals, or drums. The time-and-space matrix of human civilization had been virtually frozen ever since the almost-simultaneous invention of writing and the wheel in Mesopotamia around 3500 B.C.

But five years after the phenakistoscope, in 1838, three other time-and-space-conquering inventions burst upon the world: electrical telegraphy, steam power for ships and railroads, and photography.

Samuel Morse demonstrated the potential of telegraphy to Congress in 1838. Its speed was virtually instantaneous: Electric dots and dashes of abstracted language were sent skimming along wires at the speed of light.

In 1838, London and Birmingham were connected by steam railroad—the world's first long-distance passenger rail service. It moved at 20 miles an hour, four times faster than horse-drawn carriages. Double that speed was achieved by 1845, and double again—80 miles an hour—by 1850, when steel rails replaced wrought iron.

In that same year, 1838, the first steamship passenger service began between England and the U.S., established by Isambard Brunel's Great Western, the largest ship in the world at the time, which took only 15 days to cross the Atlantic, four times faster than the average for sailing ships.

Brunel's Great Eastern, launched in 1858, was bigger and faster still—her size and capacity were not surpassed until 1913. She could carry 4,000 passengers, and in 1866 she laid the first telegraphic cable across the Atlantic, merging steam and electricity. London could now communicate with New York at the speed of light.

UNRAVELING SPACE AND TIME

The 1830s also saw the invention and commercial application of photography, a technology that freezes time. And freezing time is the first step to controlling it. The very first photograph was taken in 1827: Joseph Niépce's view from his attic window. But it required nine hours of exposure to register the blurry image, more of a slushy than a frozen moment, but a historical one, nonetheless.

By 1838, Louis Daguerre had perfected his daguerreotype which increased clarity by several orders of magnitude and reduced the photographic exposure time to 90 seconds. By 1845, that had shrunk to a second or two, and by the end of the 19th century photographs were being snapped at a 50th of a second.

Information moving at the speed of light, travel times cut by 75 to 90 percent, photographically frozen

If at first your idea is not absurd, then there is no hope for it.

milliseconds—the apparently solid matrix of time and space that humanity had taken for granted was rapidly distorting and dissolving in a foretaste of Einstein’s relativity. But things would only accelerate: Edison’s inventions of sound recording (freezing waves of sound in mid-flight), practical electric light, and motion photography were to come in the last quarter of the century, along with Bell’s telephone, Marconi’s radio, Daimler’s automobile, and Tesla’s AC electrical energy.

Before we had time to digest any of these seemingly miraculous, Earth-shaking inventions, the 20th century rushed on with powered flight, Max Planck’s quantization of physics, and continued breathlessly with Einstein’s theories of relativity, the mass production of automobiles, a World War, radio networks, sound and color film, another World War, radar, sonar, computers, the atomic bomb, television, rocketry, jet planes, transistors, atomic energy, satellites in orbit, lasers, men on the moon, the internet, cell phones, and the discovery of exoplanets. The 21st century has so far given us the decoding of DNA, smart phones, social networking, dancing robots, streaming services, artificial intelligence, and ... as kids whine on long drives with their parents, “Are we there yet?” As my father would answer, much to my annoyance, “Probably not!”

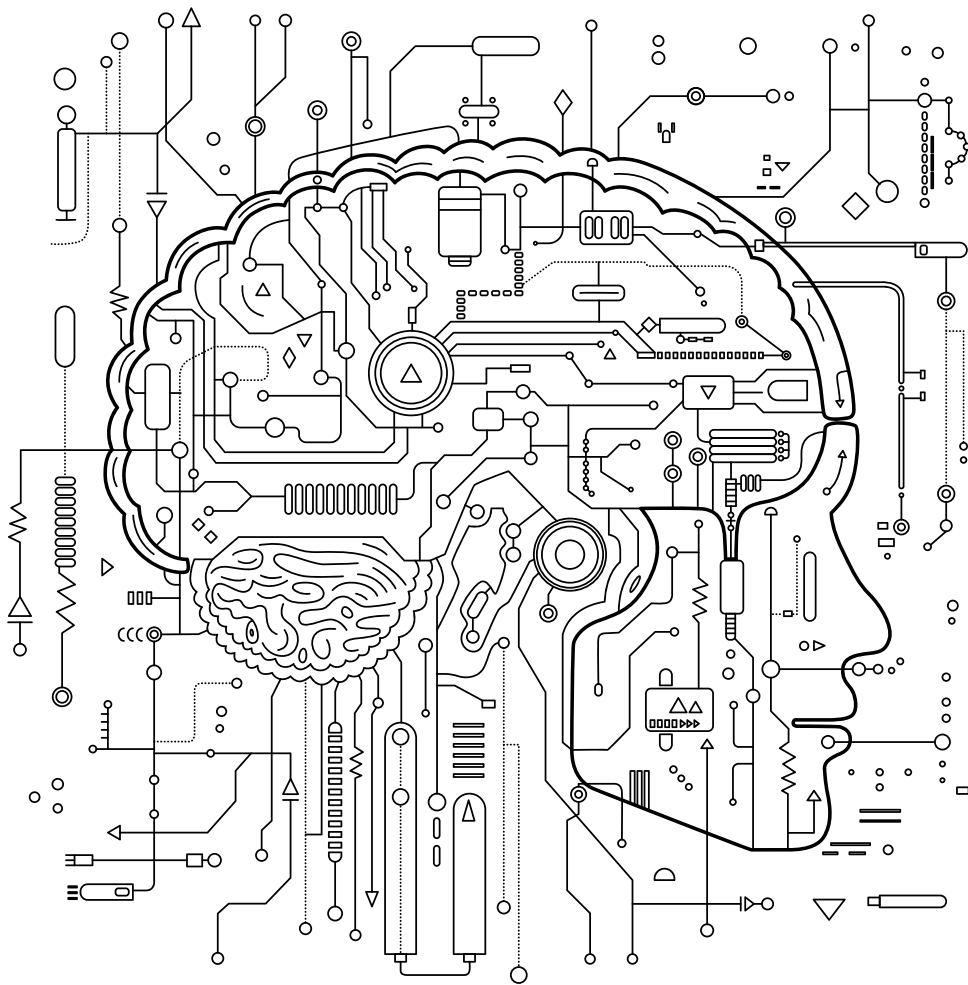
What united all those inventions and revolutions, since the first stirrings in the 1820s and ’30s, was their

ability, directly or indirectly, to unravel humanity’s previously fixed concepts of space and time. For the past two centuries, we have been totally and enthusiastically dedicated to shrinking or abolishing space and chopping or wrinkling the fabric of time—no matter what the cost or challenge involved.

Cinema not only participates fully in this unraveling process, it is one of the main drivers. Photography had made it possible to freeze time, but as a result, photographs themselves became manipulatable, leading inevitably to the invention of motion photography. And once that had been achieved, motion itself became magically malleable, either by reversing it, speeding it up, slowing it down, or interrupting and reorganizing it with editing. The cinematic cut is where the chisel of the splice cleaves the stone of time.

In his 1986 book, *Sculpting in Time*, Russian filmmaker Andrei Tarkovsky wrote that “for the first time in the history of the arts, in the history of culture, man found the means to take an impression of time. And simultaneously the possibility of reproducing that time on screen as often as he wanted, to repeat it and go back to it. He acquired a matrix for actual time. Once seen and recorded, time could now be preserved in metal boxes, theoretically forever.”

From the viewpoint of someone from the 18th century, all this would seem miraculous and absurd. But



WHAT'S NEXT? Will the next burst in creativity be the biological meshing of human beings and intelligent machines? Our evolutionary path seems fated in that direction.

as Einstein would remark: “If at first your idea is not absurd, then there is no hope for it.”

In 1895 one of the inventors of motion pictures, William K.L. Dickson, made predictions, unsupported by any of the facts at the time, about a glorious future for cinema—what he called the kinetograph—involving sound, color, and even trips to other planets.

What is the future of the kinetograph? Ask rather from what conceivable phase of the future it can be debarred! The rich strain of an orchestra, issuing from a concealed phonograph will herald the impending drama: The

JULIA ANISIMOVA / SHUTTERSTOCK

What will this furious conquest of space and time ultimately achieve?

voices will be full of mirth, pathos, command—every subtle intonation which makes up the sum of vocalism.

Some tempestuous ocean scene, quickened with the turbulent anguish of the unresting sea; the clang of arms, the sharp discharge of artillery, the roll of thunder, the sound of Andalusian serenades—all these effects of sight and sound will be embraced in the kinetoscopic drama.

Not only our own resources, but those of the entire world will be at our disposal. We may even anticipate the time when the latest doings on Mars, Saturn, and Venus will be recorded by enterprising kinetographic reporters.

Dickson wrote this before human beings had even invented powered flight, much less space travel. But his prediction did come true in 2012, 117 years later, when Curiosity Rover sent back the first motion pictures from Mars.

Viewed from this wide end of the telescope, then, it appears we student filmmakers in 1965 were simply being carried like foam on the waves of history, as all of us may be, irrespective of what we thought we might be doing—agents of the great unraveling of time and space.

Did we have free will? Perhaps. There is a difference between a human being and a fleck of foam, isn't there? But it is an eternally oscillating puzzle. What is the cause and what is the effect? Who is in control and who

controls the controller? As Issac Bashevis Singer wrote, neatly capturing the paradox, "You must believe in free will—you have no other choice."

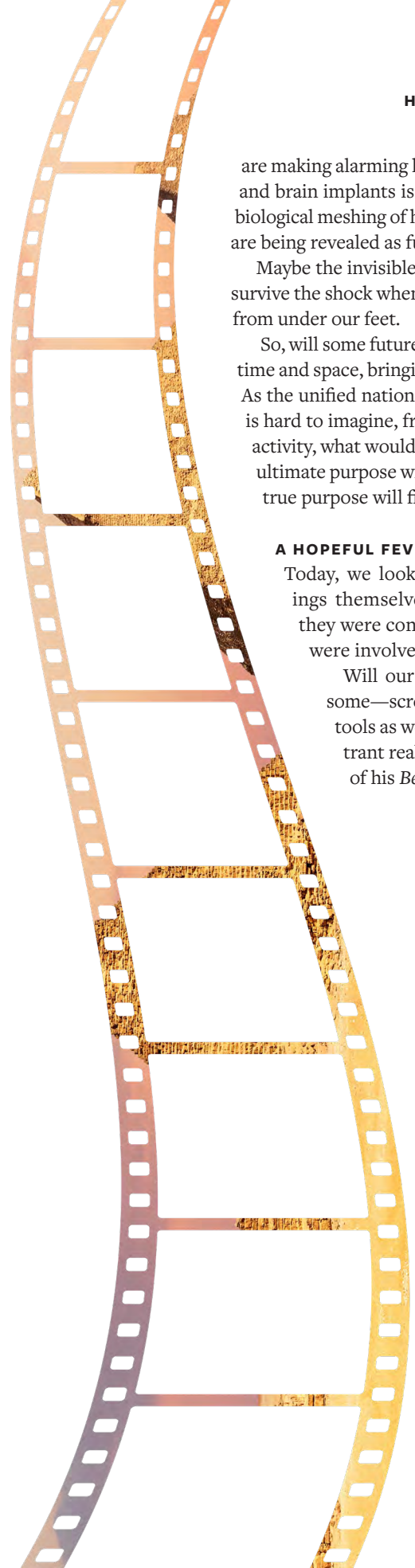
So, what will this furious conquest of space and time ultimately achieve? Why are we so feverishly dedicated to achieving it? At least with the pyramids there was a plan, and there must have been a proclamation from the Pharaoh and his priests at the temples, to which the population of Egypt responded.

But the dissolution of space and time was not proclaimed, officially, by anyone. It simply coalesced, grew, and gathered unstoppable momentum as everyone (aside from naysayers like Henry David Thoreau) seemed enthusiastic about what it offered: the realization of formerly unachievable dreams, such as instant communication across vast distances, flight, and the freezing or reversal of cinematic time.

In *The Invisible Pyramid*, Eiseley speculated, with trepidation,

That perhaps man has reached an evolutionary plateau, and to advance beyond he must either intimately associate himself with machines in a new way or give over to exosomatic evolution and transfer himself and his personality to the machine, and thus escape, or nearly escape, the mortality of the body.

This is beginning to happen. People in labs can now control the movement of screen cursors with their thoughts alone, thanks to brain implants. At the same time, virtual reality goggles and artificial intelligence



are making alarming leaps. Some kind of a fusion of virtual reality, artificial intelligence, and brain implants is looming, raising the specter of Ray Kurtzweil's "Singularity," the biological meshing of human beings and intelligent machines. Time and space themselves are being revealed as fundamental illusions by physicists.

Maybe the invisible pyramid has been acclimatizing us, over multiple generations, to survive the shock when the last threads of the time-space safety net are finally pulled out from under our feet.

So, will some future point in the 21st century mark the end of our human experience of time and space, bringing to a climactic end these two centuries of feverish achievement? As the unified nation-state lay on the other side of the pyramid age, what awaits us? It is hard to imagine, from our perspective today, still caught in the froth of such furious activity, what would lie on the other side of the Singularity. But the invisible pyramid's ultimate purpose will only be fully revealed when the wave recedes. Then, perhaps, its true purpose will finally become visible.

A HOPEFUL FEVER DREAM

Today, we look at creations like the pyramids not only in awe of the buildings themselves, marvels of architecture, but also in astonishment at how they were constructed: human muscle and copper tools—no wheels or horses were involved.

Will our descendants 4,000 years from now—and I pray that there are some—screen our films and appreciate what we accomplished with our paltry tools as we struggled to forge insubstantial dreams out of the iron of recalcitrant reality? A struggle Jean Cocteau described in 1946, during the making of his *Beauty and the Beast*.

Try to hold the threads of this enormous and delicate mechanism in your hands; subdue all the dust, independent wills, ingenious disorder; call for action, interrupt it (because of a broken thread), resume, and never lose hold of the big picture.

Perhaps by then our descendants will have discovered some new forces of nature that would be as powerful and as mysterious to us as electromagnetism and nuclear energy would have been to the ancient Egyptians.

And rather than light, our far-distant children will take our films and beam this new energy through the images, seeing not the pictures themselves, but a dynamic multidimensional pattern—endlessly fascinating because its swirling beauty will somehow reveal to them the intricate and powerful interplay of all the influences and personalities that improbably came together, sometimes in harmony, sometimes in conflict, to shepherd the film—Cocteau's "enormous and delicate mechanism"—along its path from dream to reality.

"How did they do it," they will wonder, shaking their heads, "when they didn't know about χ or ψ , or even ζ ? Incredible!"

Back here in the present, we know that every film we make is the complex product of myriad influences and personalities, ranging from the accidentally trivial to ingenious disorder, the serendipitously coincidental to the existentially profound. But the true sources and detailed interplay of those internal organs of creativity remain mostly hidden, even from us filmmakers, as they move and mingle mysteriously under the glossy skin of the film. ☺

WALTER MURCH's six decades in cinema as film editor, sound mixer, writer, and director include work on *The Godfather* trilogy, *American Graffiti*, *The Conversation*, *Apocalypse Now*, *The English Patient*, *The Talented Mr. Ripley*, *Cold Mountain*, and many other films. Murch has been nominated for nine Academy Awards and has won three Oscars: for Best Sound on *Apocalypse Now* and for Best Film Editing and Best Sound for his work on *The English Patient*. This essay is adapted from his book, *Suddenly Something Clicked*, to be published in 2025.



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Crying Wolf in an Age of Alarms

The human costs of faulty disaster warnings

BY BENJAMIN CASSIDY

IN RURAL WASHINGTON, on a dry July morning in 2020, Collienne Becker stood at the edge of her driveway and prepared to face a wall of water.

Minutes earlier, she'd stepped onto the porch of her farmhouse to smoke a cigarette when she heard a familiar, jolting sound. Every Wednesday at noon for as long as anyone in the town of Carnation could remember, a high-pitched siren had blared in the small city, followed by a weekly dose of reassurance over a loudspeaker: "This is a test of the Tolt Dam Warning System."

For decades, the City of Seattle has owned and operated, from afar, the Tolt Reservoir and Dams, which supplies about a third of greater Seattle's drinking water. Carnation—a small farming community of just over 2,000 people in the Snoqualmie Valley, about 30 miles east of the city—receives none of that water, but bears all of the risk of the operation. In the improbable event that the 200-foot-high dam fails, a 30-foot wave of water could surge down the South Fork Tolt River and inundate this small town.

Since the time they're children, locals learn that an alarm on Wednesday at noon is nothing to worry about: It's just routine testing—everything is fine. But if the siren sounds at any other time during the week, it's reason to head for higher ground immediately.

This time, it was a Tuesday. A message over the alarm's accompanying speaker confirmed everyone's fears: "The Tolt Dam has failed. Evacuate the area immediately."



“I’m going to die,” she thought.

Becker, who had recently retired from Amazon, and her husband, Michael, scrambled to grab food and water and leashes for their howling golden retrievers. Yet, by the time they corralled the animals into their Toyota 4Runner, the typically vacant road abutting their property was already bumper-to-bumper. Roaring fire trucks had alerted families to scoop up their kids. They had an hour, tops, to leave town or climb to a higher elevation.

With most of the traffic heading west, away from the reported deluge, Becker decided, somewhat counterintuitively, to drive east toward the dam. The couple had friends who lived in the thickly forested highlands nearby. They could hole up there, potentially. But she only made it a mile. A woman driving a horse trailer had jackknifed across the narrow country road and gotten stuck, blocking it for everyone, after a passerby said a bridge nearby had breached and she needed to turn around.

So Becker doubled back, illegally driving westbound in the empty eastbound lane, incredulous that people were still waiting for the traffic light in the other lane

when they could potentially drown at any moment. When she reached home, she walked down her driveway, and, with traffic westbound out of town at a standstill, decided to await her fate. She imagined their farmhouse, one of the oldest structures in the area, getting swept away. She imagined worse. *I’m going to die*, she thought.

“That’s when a guy said, ‘Oh, it’s all false. Don’t worry about it,’” says Becker. As she stood immobilized in her driveway, he leaned from his car and told her he’d seen a Facebook post that suggested the siren was a false alarm. Becker wasn’t sure whether to trust him, but a sheriff soon came by and confirmed the rumor. A crew working on the warning system had accidentally set it off. Everyone could go home.

The siren, which blared for more than 40 minutes, was the first and most harrowing of eight false alarms that sounded over a four-year span in Carnation. These repeated false alarms left residents with lingering stress, anxiety, and jangled nerves.

In August 2023, after the sixth failure of the alarm, the city declared a state of emergency, imploring Seattle officials to fix the problem. “Seattle’s dam puts all of



our lives and property at risk,” Jim Ribail, Carnation’s mayor, told Seattle City Council that September. But even as Seattle Public Utilities has worked to improve the faulty warning system with new technology and equipment, they can’t alleviate the psychological toll it has already taken. “There are many people that live here today that still suffer from the PTSD [of] this first event,” Ribail said during a community forum later that month.

In the aftermath, some locals have taken measures to protect their mental health. One resident on the autism spectrum sets a timer for two minutes before the test siren on Wednesdays to mitigate his agitation. Becker, meanwhile, leaves town entirely on Wednesdays—every Wednesday. Once a standard, if still jarring, interjection in the quiet rhythm of the town, the siren is now “a trigger,” she says—an anxiety-inducing reminder of that awful day.

Beyond the haunting psychological effects, however, a more insidious and potentially damaging response to the spate of false alarms has also set in across Carnation: There have been so many false alarms, Becker says, that she and others are experiencing “the ‘cry wolf’ thing.” She says, “If it had went off today, I would have probably had that rush of panic, but I would have waited to try to figure out whether it was real or not. Waiting is probably not the right decision, but I just don’t trust it anymore.”

She’s not the only one. Each time the alarm sounded in Carnation, Ribail hopped in his truck and drove up to a 20-acre evacuation site in the Tolt Highlands. Each time, the mayor has waited for his constituents to join him there, only to discover “nobody’s coming up,” he says.

AS EXTREME WEATHER EVENTS become more commonplace, cities around the globe are working to set up more early warning systems. Reported weather related disasters increased almost fivefold from 1970 to 2019, while economic losses related to those disasters rose nearly sevenfold, according to a recent World Meteorological Organization report.

But over that same timespan, deaths from weather related disasters dropped by a factor of three. The WMO attributes the higher survival rates to improved disaster management and more early warning systems—in areas with fewer reliable forecasts and

EXIT PLAN A 20-acre evacuation site in the Tolt Highlands is meant to protect residents of Carnation, Washington, against a failure of the 200-foot-high Tolt dam, which is 16 miles upstream on the South Fork Tolt River. In the improbable event that the dam fails, a 30-foot wave of water could surge down the river and inundate the town.



Subscribers received three alerts that killer doll Chucky was on the loose.

warnings, the rates of fatalities are higher. In 2022, the United Nations launched an “Early Warnings for All” initiative to “ensure that early warning systems protect everyone on Earth by 2027.”

But not all warning systems are created equally. Natural disaster alerting systems are generally more accurate than they once were but remain fallible, so those designing new systems have to ask themselves: What are the consequences of too many alarms versus too few? How frequently and under what circumstances should an alarm go off? And how can we protect these systems from embarrassing hacks, such as the one that occurred in Texas in 2021, in which subscribers received three alerts that killer doll Chucky was on the loose?

In our era of climate change, “having warnings that actually make people evacuate becomes more and more important,” says Katharina Hembach-Stunden, a researcher who worked on a recent study of the cry wolf effect while at Osnabrück University in Germany.¹ “If you have too many false alarms, there’s a lot of research that hints toward people becoming more reluctant to actually respond to it. So you’ve run this risk of them not evacuating and then having higher losses—deaths.” Changing behavior is difficult, she says.

AS LONG AS THE ANCIENT STORY of the boy who cried wolf has circulated, common sense has dictated that the public won’t believe a liar—even when he or



she is telling the truth. One of Aesop's most famous fables centers on human morality, but it has long guided the popular understanding of how people interpret false alarms from insentient sources, too.

The story's lesson was committed to the annals of psychological research in the 1980s when Holocaust survivor and University of Haifa professor Shlomo Breznitz applied his expertise on stress to false alarm responses. Warning systems had become increasingly prevalent in fields such as meteorology and defense, he observed in his 1984 book, *Cry Wolf: The Psychology of False Alarms*. But these detectors still leaned on an external variable—their credibility—to achieve their intended effect. Through laboratory experiments that involved threatening, and then canceling, painful shocks, Breznitz found that every false alarm reduced the perceived trustworthiness of alert systems.

The book has served as a foundational text for contemporary research on what's now known as the “cry wolf effect,” which contends that a warning system's credibility loss from a false alarm leads to complacency. In the face of emergencies, this effect manifests in a lack of protective action, such as sheltering in place or evacuating.

Some scholars have found evidence of the cry wolf effect in medical monitoring and natural disaster responses. Repeated false alarms in intensive care units can lead to alarm fatigue among nurses, which can compromise patient care and raise the risk of accidents and death. And a high regional rate of false alarms from the National Weather Service has been linked to increases in natural disaster injuries and fatalities.²

But it seems humans don't always behave as the folklore suggests. “Despite expectations to the contrary, much of the hazards literature suggests no cry wolf effect or negative influence of false alarm on household perceptions and behavior,” wrote disaster and weather scientists in a 2015 issue of *Weather, Climate, and Society*. This was true, they found in their literature review, for hurricanes, tornadoes, and floods.

In 2019, a National Oceanic and Atmospheric Administration study further complicated the conventional wisdom.³ NOAA wanted to examine false alarms for tornados because of the potentially deadly consequences and high frequency of these natural disasters; about three-quarters of National Weather Service

tornado warnings end up being false alarms, the greatest ratio for any natural disaster.

Surveys of more than 4,000 southeastern United States residents discovered that people are very bad at estimating how often an alarm is false and that, even in areas with high numbers of false alarms, residents still sought shelter at among the highest rates.

“There's mixed findings in that research, which is what makes it so interesting,” says Sarah DeYoung, a professor in the University of Delaware's Disaster Research Center who was not part of the NOAA study. “In some communities, it's led to hyper vigilance. In some communities or instances in some studies, it's led to reduced vigilance.”

The different types of hazards and communities in these studies likely helps to explain the disparate results, according to DeYoung. For instance, how one might respond to an alarm for a tornado in a region accustomed to them may not be a good analogue for, say, how one would respond to an alarm warning of an unprecedented dam breach, says JungKyu Rhys Lim, who contributed to the NOAA study while he was a researcher at the University of Maryland.

But Lim says a far more unusual false alarm that happened in Hawaii recently reminds him of Carnation's plight.

SINCE 2012, VARIOUS U.S. GOVERNMENT authorities have sent tens of thousands of text message-like Wireless Emergency Alerts to inform different areas of crises such as missing children and severe weather. But at 8:08 a.m. on Jan. 13, 2018, residents of Hawaii received one unlike any before or since: “BALLISTIC MISSILE THREAT INBOUND TO HAWAII. SEEK IMMEDIATE SHELTER. THIS IS NOT A DRILL.”

It would be another 38 minutes before the government sent another alert with the professional equivalent of “just kidding.” Like in Carnation, a local agency was responsible for accidentally activating a false alarm.

Before the follow-up message, confusion reigned on the state's constellation of islands. Locals wondered whether they were about to endure another Pearl Harbor. Some assumed it had been sent in error. Others called loved ones, thinking they were about to die, and desperately sought more information. A few were more fatalistic, wandering to the beach to drink wine.





CROSSROADS Carnation, Washington, is a small farming community of just over 2,000 people in the Snoqualmie Valley, about 30 miles east of Seattle. In August 2023, after the sixth failure of an alarm meant to warn residents of failure of the Tolt Dam, the city declared a state of emergency.

These responses and the aftermath show the wide variety of ways humans may react to the same incident. In a follow-up study in *International Journal of Disaster Risk Reduction*, for example, at least one survey respondent reported he could never trust the Hawaii Emergency Management Agency again, while others said they'd be more prepared to take precautions for the next missile alert.⁴

This dichotomy persists in Carnation, too. Kira Avery, the executive director of the Sno-Valley Senior Center, says the organization has a greater understanding of evacuation protocols now to protect some of the area's most vulnerable residents. "It has definitely prepared us more," she says.

When the first false alarm siren went off in Carnation in July 2020, Avery remembers looking behind the senior center at the city offices. She saw workers there getting in cars to evacuate. "It was then when we realized, 'Okay, this is not a test. We need to leave.'" Similarly, the town's mayor, Ribail, who was in nearby

IAN DEWAR PHOTOGRAPHY / SHUTTERSTOCKW



Some called loved ones, thinking they were about to die. A few wandered to the beach to drink wine.

Redmond at the time, dialed Carnation's treasurer to confirm the danger. "This is real," she told him.

Sharing information with others nearby to better understand a threat and its potential implications—also known as “milling”—was a common reaction in Hawaii, too, the survey found. Neighbors there conferred in driveways and messaged online, suggesting that before people decide to react to an alarm, they may consult others in the community rather than just rely on independent judgment. “I’ve noticed, across all my research and in my personal life, people do that social milling thing, where they’re going to look to see what other people are doing,” says DeYoung, who was one of the authors of the Hawaii paper.

Those who went online usually found reassurance sooner. Some saw posts by Hawaii congresswoman Tulsi Gabbard that dispelled the missile myth. But others bemoaned the lack of physical cues around them. “A lot of people talked about listening for or noticing a lack of air raid sirens,” says Jennifer Trivedi, an

assistant professor in the University of Delaware's Disaster Research Center who conducted interviews on the ground after the false missile alert.

A similar complaint would resurface five years later, after the Maui wildfires. The island has 80 siren towers—when natural disaster is imminent, they're designed to blast long tones to let the public know to seek more information on radio or television and to evacuate to higher ground, head inland, or if they are inside a concrete building, to climb to the fourth floor or higher. The sirens are tested routinely, each month. But during the blazes, officials decided not to activate them at all—in part, for fear that residents would head into the hills, putting them at greater risk. Instead, they sent out only phone notifications. But many people never received these digital alerts, inviting a different but nagging question: How can we manage—and measure the efficacy of—alarms in an era of increased natural disasters if some people never hear the cry?



How can we manage alarms in an era of increased natural disasters if some people never hear the cry?

The roots of that question date back to the 1960s. At the time, scholars David Green and John Swets had just formulated what is known as signal detection theory, which proposed a framework for how people respond to stimuli, or signals—such as disasters—in situations of uncertainty. If they perceive a signal—say, a flood—but don’t get an alarm, it’s a “miss.” If they get an alarm, but no flood occurs, it’s a false alarm. Neither is a desired outcome, but which is worse over the long run?

In a study published in *Q Open: A Journal of Agricultural, Climate, Environmental, Food, Resource, and Rural Development Economics*, researchers examined how individuals would respond to an alarm system that frequently missed events—giving a “safe” forecast ahead of a dangerous storm—versus one that frequently issued false alarms related to seasonal forecasts. In an online experiment that sought to test this idea through simulated scenarios, subjects received probabilities for normal and extreme seasons and were allocated “points” to pay for protection. Over a series of 10 seasonal projections and prompts, researchers found that false alarm-prone forecasts led to less investment in adaptation than more accurate ones—the cry wolf effect, in other words.

But with alarm systems prone to miss weather events, they observed more investment in adaptation,

regardless of whether a warning was issued. Essentially, participants stopped trusting the safe forecasts.

When designing a forecast and a warning system, engineers and policymakers have to find the right balance between false alarms and missed alarms, says Hembach-Stunden, the lead author of the study, because both come with some long-term costs. “Finding the right balance is very dependent on what is at risk,” she says. “So I see a big challenge there for people who are making the decisions on how these forecasts or warning systems should be designed.”

Jeannette Sutton, an associate professor at SUNY Albany who studies disaster warnings, says relying on just one warning system can be dangerous. Started in 2012, Wireless Emergency Alerts, for example, were sent to phones more than 84,000 times in their first decade of existence. But emergency managers for different parts of the U.S. have different policies and thresholds for delivering these text-like warnings, Sutton says. Bombarded users can opt out of them entirely; too many missing person alerts, say, could lead to someone to turn the alerts off or tune out—and then miss one for a deadly tornado. “I don’t think that we think broadly enough about how our actions in one place are going to affect another place,” says Sutton.



EARLY LAST FALL, Carnation finally received some good news about its own siren problem. Seattle would be replacing the outdated Tolt Dam Early Warning System with a new one that October. “We value protecting life through our services that we provide, and clearly we have failed in doing that for all of you,” Seattle Public Utilities general manager and CEO Andrew Lee told the crowd at the community forum in late September.

But no sooner had SPU installed a new system than it had introduced a new problem: The alarm wasn’t loud enough. Local officials and neighbors swiftly gathered for a press conference along a trail where a new siren, shaped a bit like a honey dipper, rose between evergreens. “Even for me, living right across the street from it, it’s far more difficult to hear and understand compared to the previous one,” one resident said. Another local added that they had to pause conversation in downtown buildings to make out the alarm.

Since the initial rollout, SPU has upgraded its sirens. It’s also slated to add more indoor alerting devices, evacuation signs, and highway messages this year. But in late March, the alarm went off again, the eighth false alarm in four years.

These false alarms continue to take a serious psychological toll.

When SPU announced it would test the new system in Carnation this coming fall over multiple days, it was easy for Becker to schedule a trip to Nevada. “I couldn’t stand hearing it,” she says, “because it sends me back to that day every time.” When the dam’s warning system went off that first time in July, her father had recently died. She called her mother for what she thought would be the last time.

Becker has considered moving but stresses that she’s a “strong-willed person.” About two decades earlier, when she was working in one of Amazon’s corporate high-rises downtown, she felt the Nisqually earthquake rattle the building. “I don’t let that kind of thing bother me. I just don’t,” she says. But her experience with the Tolt Dam false alarm, she says, hit her differently. “I can’t shake it. And I don’t know why.” ☹️

BENJAMIN CASSIDY is a freelance journalist based in Seattle. His work has appeared in *National Geographic*, *Scientific American*, and *The Seattle Times*, among other publications. You can find out more about him and his writing at bybencassidy.com.

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The “Hot Hand” Is Not a Myth

A mathematician revisits the famous paper that claims a player's hot streak in sports is an illusion

BY AUBREY CLAYTON

IN A RECENT INTERVIEW for the web series *Hot Ones*, where guests answer tough questions while eating super-spicy chicken wings, pro basketball superstar Stephen Curry was asked about a sports psychology study from the 1980s. The subject of the study was the “hot hand effect,” the idea that players’ successes come in streaks—dependent on some mysterious inner quality that ebbs and flows—and when a player’s hand is hottest and they’re “in the zone,” it can feel almost like they can’t miss.

Curry knows a thing or two about a hot hand. He holds the NBA record for making at least one three-pointer in 268 consecutive games. Following a practice one day, he sank 105 three-pointers in a row. In the *Hot Ones* interview, Curry said the authors of the study “don’t know what they’re talking about at all.” When Curry totaled 60 points in one game, he said, “It’s literally a tangible, physical sensation of all I need is to get this ball off my fingertips and it’s going to go in.”

The study, “The Hot Hand in Basketball: On the Misperception of Random Sequences,” was written in 1985 by eminent psychologists Thomas Gilovich, Robert Vallone, and Amos Tversky. They allegedly demonstrated through an analysis of basketball shooting

data that the hot hand was a myth. Recently deceased Nobel laureate (and Tversky’s chief collaborator) Daniel Kahneman proclaimed, “The hot hand is a massive and widespread cognitive illusion.” In statistical circles, the hot hand study has taken on a metaphorical significance beyond basketball. For decades, the fallacy of the hot hand has been cited to show that folktales of luck and streakiness are no match for cold, hard numbers.

However, the numbers do not prove the hot hand is a figment of imagination. Economists Joshua Miller of the University of Melbourne and Adam Sanjurjo at the University of Alicante in Spain, used data from multiple basketball leagues, including the same data used by Gilovich, Vallone, and Tversky, to provide robust

Shouldn't years of testimony from athletes like Stephen Curry count for something?

support for a hot hand. The problem, say Miller and Sanjurjo, lies in the way the original authors analyzed their data and, in particular, a mistake they made about what random data should look like *without* the influence of a hot hand.

The mistake is this: Imagine we're looking at a chart of hits and misses over some number of shots and trying to find where a shooter might have had a hot hand. Suppose we look for hot-handedness by considering *only* those attempts that came after a sequence of hits, such as three baskets in a row. These sequences are candidates for being shot with a "hot hand."

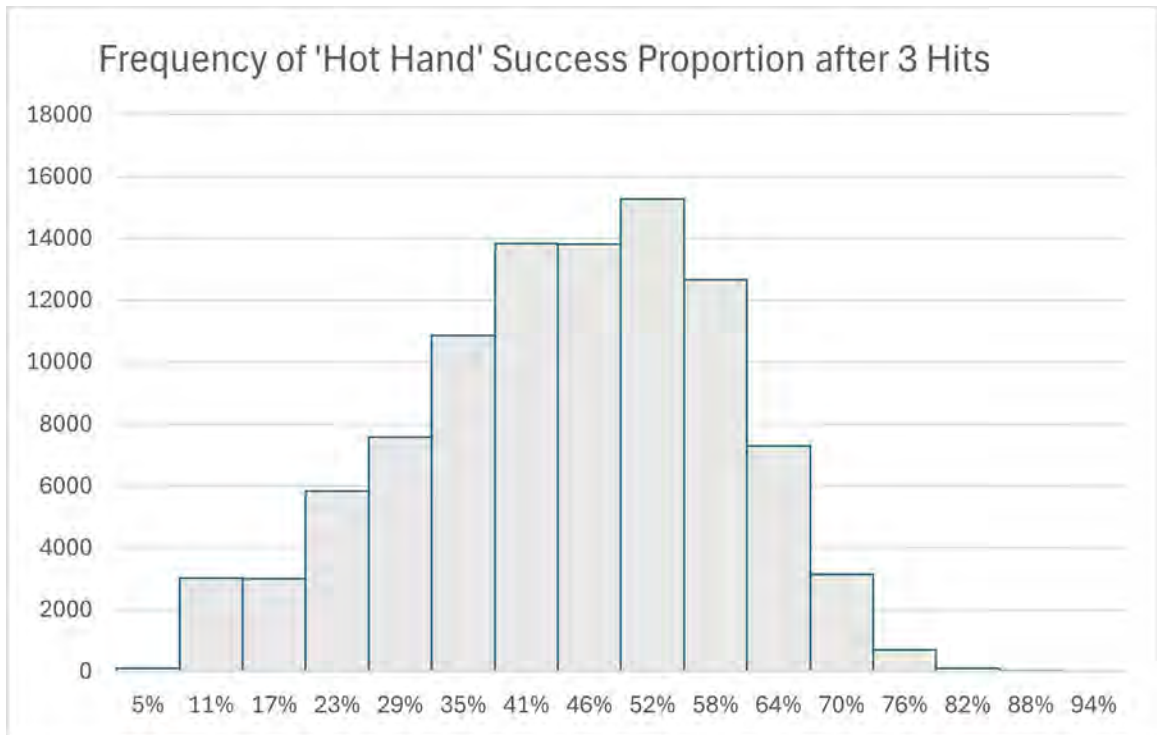
However, if there's no such thing as a hot hand, we might expect the player to have the same success rate in these attempts—the shots after three consecutive makes—as their overall average. Since our working theory is that the previous successes have no predictive power for the next shot, it would seem intuitive that our choice of shots based on what happened right before the hot streak shouldn't matter at all.

But that's wrong. By selecting attempts that come after a hot streak and computing a proportion over this subset, we have unwittingly introduced a negative bias into the estimate of the rate of success that could counteract a hot-hand-induced positive effect. In other words, the observed percentage of success-following-success being equal to the rate of success-following-anything, would be evidence for the hot hand instead of against it. The way we selected the data artificially penalized the shooter; their true success rate may have

been a few percentage points higher than what we tabulated. So, if our observation matched their usual average, it must be that something else was at work to offset our bias—a hot hand.

If you find yourself doubting this bias exists, you're in good company, including the esteemed professors who first "debunked" the hot hand. Like other famously counterintuitive examples in probability, such as the Monty Hall Problem—the puzzle of whether to switch doors when searching for a prize on the game show *Let's Make a Deal*—the phenomenon acts almost like an optical illusion: Our natural senses tell us something that turns out to be contradicted when we try to confirm it with hard measurement.

I'll freely admit that I didn't believe it either, at first. I only became convinced after I ran 100,000 simulations of 100 random coin flips and tabulated the proportions of heads following streaks of three heads. I knew the coin flips were perfectly random 50/50 processes under any conditions (coins don't get "hot"). So, if I estimated the success rate at anything less than 50 percent, the bias was real. The overall average proportion of heads-after-three-heads I got was around 46 percent. The histogram (data visualization) of results clearly showed the negative bias. Without understanding the source of the bias, we might think the coin had the opposite of a hot hand. This was mechanically the same procedure as the original 1985 study, showing the study was flawed and its conclusions likely invalidated.



To see how this could possibly work, consider a simplified example of three coin flips. Suppose we want to determine if a coin coming up heads is more likely to be followed by another heads—to see if the coin can get “hot.” There are eight equally likely sequences of flips:

HHH
HHT
HTH
HTT
THH
THT
TTH
TTT

Out of these, the proportions of heads being followed by heads are as follows:

1
 $\frac{1}{2}$
0
0
1
0

N/A

N/A

(We discard the last two cases because no coin flip came after a head.) Averaging the estimated proportions over the remaining six cases yields $(1 + \frac{1}{2} + 1)/6 = 5/12$, or about 42 percent. That is decidedly less than 50/50.

Even though we know the coin has no memory or “momentum,” estimating this way produces a number less than the true success probability in these situations, on average. As Miller and Sanjurjo demonstrated, this bias gets larger when you consider smaller samples and longer streaks. In the typical experiments like those in Gilovich, Vallone, and Tversky’s work, looking at streaks of two or three in samples of around 100, it could make a sizable difference.

Now, we might expect some strange things to crop up when we process the data the way I have described above. For one thing, we’re talking about an average proportion: the average over all the possible universes of the proportion of attempted shots that were successful after a streak of hits. Further, “average proportions”

The numbers do not prove the hot hand is a figment of imagination.

are notoriously finicky, especially when the proportions are being computed over different numbers of events, as they are here.

In some sequences of coin flips in the table above, we had two cases to consider (such as the first and second ones) while in others there was only one. Compiling proportions taken over different sized sets is how we get famous examples of weird behavior like “Simpson’s Paradox,” in which a variable may trend one way among subsets of a larger group while the overall trend is the opposite.

For another thing, in our dataset of hits and misses, some of the streaks we might be considering necessarily overlap with each other. For example, if somewhere in the midst of 100 coin flips we had the sequence HHHHT, this would account for two streaks of three heads, one that’s followed by another heads and a second followed by tails. This means, in fact, that unless the segment we’re currently considering lasts until the very end of the data, there must at some point be a streak that ends in failure. The necessity of these failures contributes to the negative bias in our estimate of the rate of success.

Of course, real-world data is not like an idealized sequence of coin flips, and in a team sport like basketball, the picture is made messier thanks to confounding variables. This is due to an overall lack of available data from real games, and the fact that, often, when a player gets hot, defenses will change their strategy to compensate.

What’s more, a player on a shooting streak, who may have a hot hand or not (some streaks are just luck), may take greater risks, such as attempting more difficult shots, known colloquially as “heat checks.” If these attempts result in misses, then a look at just the data would suggest the player was never hot. Some players may get nervous after a few successes because they feel all eyes are on them, whereas for others the pressure of a big game or a cheering crowd may be integral to the emergence of a hot hand. Controlled experiments where the strategic factors are held fixed but the psychological environment is preserved are hard to come by.

That’s why Miller and Sanjurjo claim perhaps the strongest evidence for the hot hand effect is in the three-point shooting contest, held during the NBA’s

All-Star weekend festivities; there's no defense and the shot locations are fixed. Players have 70 seconds to shoot up to 27 balls. Performances like Craig Hodges hitting 19 shots in a row in 1991 seem like clear examples of a hot hand at work. (Curry has won the contest twice.) From there, Miller said, it's reasonable to extrapolate to in-game settings, and "then you can couple that with what the players themselves say." Or do. "This guy shot the basketball and started walking the other way," commentator Mark Jackson once remarked during a game after Dwyane Wade, the former Miami Heat star, launched a three-pointer with such confidence that he didn't bother to watch it go in. "That's called being in the zone."

However, there's the crux of the issue: Should we trust people's subjective experiences of what it's like to be "in the zone," or should we assume there's no such thing until it shows up in the data? Cognitive biases, such as finding patterns where none exist, are certainly real, and people's ability to discern the presence of randomness is notoriously bad. Go to any casino and watch at the roulette table as people try to spot streaks in the most recent spins or look online for advice about tradeable "signals" in the movements of stock prices. But shouldn't years of testimony from high-performing athletes like Curry count for something?

The claim that the hot hand is an illusion is equivalent to saying players' skill levels are perfectly constant through time. Compared to the hot hand effect, this is arguably the bolder statement in need of evidentiary support. Many human activities—from sports to literature to theoretical physics—involve some combination of skill and luck to create success. But it's misleading to think of the "luck" component of that mix as truly "random."

Instead, it's perhaps better described as uncontrollable by the person involved in performing the action—the tiny fluctuations in the conditions of the ball, fingers, arms, feet—the unaccounted-for variations and moments of inspiration that are beyond the skill level of that particular player to reliably dictate at that particular moment.

But who's to say the boundary between controllable and uncontrollable can't shift? The relative shares of "luck" vs. "skill" could be dependent on many situational factors. Players might reliably be able to sense

when finer details that are normally beyond their control are suddenly within their grasp. That's "the zone."

The saga of the hot hand effect offers at least one final cautionary tale about the enduring power of random phenomena to fool us all (myself included), even—maybe especially—when we think we're unfoolable. The counterintuitive properties of streaks in random sequences tricked the original researchers into overlooking a pattern that was really there in the data. The percentage of successes under their method of selecting candidate shots included a bias that erased the effect of the hot hand to boost the success rate.

But by simulating synthetic data under known assumptions and verifying that their methods retrieved the right answers, they might have protected themselves against the illusions of probability. Tversky, after publishing his research and becoming one of the most outspoken critics of the hot hand, once said as much: "It may be that the only way you can learn about randomness is to toss coins on the side while you play." The next time you watch a basketball game, and happen to notice any players on the bench compiling histograms of coin tosses, they might just be trying to understand whether it's statistically valid to conclude their teammates are heating up. 🌀

AUBREY CLAYTON is an applied mathematical researcher, lecturer, and writer. He is the child of two math teachers and the author of *Bernoulli's Fallacy: Statistical Illogic and the Crisis of Modern Science*.

What Counts as Consciousness

Neuroscientist Christof Koch on human minds, AI, and bacteria

BY DAN FALK



SOME YEARS AGO, when he was still living in southern California, neuroscientist Christof Koch drank a bottle of Barolo wine while watching *The Highlander*, and then, at midnight, ran up to the summit of Mount Wilson, the 5,710-foot peak that looms over Los Angeles. After an hour of “stumbling around with my headlamp and becoming nauseated,” as he later described the incident, he realized the nighttime adventure was probably not a smart idea, and climbed back down, though not before shouting into the darkness the last line of William Ernest Henley’s 1875 poem “Invictus”: “I am the master of my fate / I am the captain of my soul.”



It may be that a little bacterium feels a little bit like something.

Koch, who first rose to prominence for his collaborative work with the late Nobel Laureate Francis Crick, is hardly the only scientist to ponder the nature of the self—but he is perhaps the most adventurous, both in body and mind. He sees consciousness as the central mystery of our universe, and is willing to explore any reasonable idea in the search for an explanation.

Over the years, Koch has toyed with a wide array of ideas, some of them distinctly speculative—like the idea that the internet might become conscious, for example, or that with sufficient technology, multiple brains could be fused together, linking their accompanying minds along the way. (And yet, he does have his limits: He’s deeply skeptical both of the idea that we can “upload” our minds and of the “simulation hypothesis.”)

In his new book, *Then I Am Myself the World*, Koch, currently the chief scientist at the Allen Institute for Brain Science in Seattle, ventures through the challenging landscape of integrated information theory (IIT), a framework that attempts to compute the amount of consciousness in a system based on the degree to which information is networked. Along the way, he struggles with what may be the most difficult question of all: How do our thoughts—seemingly ethereal and without mass or any other physical properties—have real-world consequences? We caught up with him recently over Zoom.

In your new book, you ask how the mind can influence matter. Are we any closer to answering that question today than when Descartes posited it nearly four centuries ago?

Let’s step back. Western philosophy of mind revolves around two poles, the physical and the mental—think of them like the North and South poles. There’s materialism, which is now known as physicalism, which says that only physical really exists, and there is no mental; it’s all an illusion, like Daniel Dennett and others have said.

Then there’s idealism, which is now enjoying a mini-renaissance, but by and large has not been popular in the 20th and early 21st century, which says that everything fundamentally is a manifestation of the mental.

Then there is classical dualism, which says, well, there’s clearly physical matter and there’s the mental, and they somehow have to interact. It’s been challenging to understand how the mental interacts with the physical—that’s known as the causation problem.

And then there are other things like panpsychism, that’s now becoming very popular again, which is a very ancient faith. It says that fundamentally everything is “ensouled”—that everything, even elementary particles, feel a little bit like something.

All of these different positions have problems. Physicalism remains a dominant philosophy, particularly in

Western philosophy departments and big tech. Physicalism says that everything fundamentally is physical, and you can simulate it—this is called “computational functionalism.” The problem is that, so far, people have been unable to explain consciousness, because it’s so different from the physical.

What does integrated information theory say about consciousness?

IIT says, fundamentally, what exists is consciousness. And consciousness is the only thing that exists *for itself*. You are conscious. Tonight, you’re going to go into a deep sleep at some point, and then you’re not conscious anymore; then you do not exist for yourself. Your body and your brain still have an existence for others—I can see your body there—but you don’t exist for yourself. So only consciousness exists for itself; that’s absolute existence. Everything else is derivative.

It says consciousness ultimately is causal power upon itself—the ability to make a difference. And now you’re looking for a substrate—like a brain or computer CPU or anything. Then the theory says, whatever your conscious experience is, what it feels like to see red, or to smell Limburger cheese, or to have a particular type of toothache—maps one-to-one onto this structure, this form, this causal relationship. It’s not a process. It’s not a computation. It’s very different from all other theories.

When you use this term “causal powers,” how is it different from an ordinary cause-and-effect chain of events? Like if you’re playing billiards, you hit the cue ball, and the cue ball hits the eight ball ...

It’s nothing woo-woo. It’s the ability of a system, let’s say a billiard ball, to make a difference. In other words, if it gets hit by another ball, it moves, and that has an effect in the world.

THE SELF In his new book, neuroscientist Christof Koch grapples with the complexity of consciousness.

And IIT says you have a system—a bunch of wires or neurons—and it’s the extent to which they have causal power upon themselves. You’re always looking for the maximum causal power that the system can have on itself. That is ultimately what consciousness is. It’s something very concrete. If you give me a mathematical description of a system, I can compute it, it’s not some ethereal thing.

So it can be objectively measured from the outside?
That’s correct.

But of course there was the letter last year that was signed by 124 scientists claiming that integrated information theory is pseudoscience, partly on the grounds, they said, that it isn’t testable.

Many years ago, I organized a meeting in Seattle, where we came together and planned an “adversarial collaboration.” It was specifically focused on consciousness.



It's not my brain that sees; it's consciousness that sees.

The idea was: Let's take two theories of consciousness—in this case, integrated information theory versus the other dominant one, global neuronal workspace theory. Let's get people in a room to discuss—yes, they might disagree on many things—but can we agree on an experiment that can simultaneously test predictions from the two theories, and where we agree ahead of time, in writing: If the outcome is A it supports theory A; if it's B, it supports theory B? It involved 14 different labs.

The experiments were trying to predict where the “neural footprints of consciousness,” crudely speaking, are. Are they in the back of the brain, as integrated information theory asserts, or in the front of the brain, as global neuronal workspace asserts? And the outcome was very clear—two of the three experiments were clearly against the prefrontal cortex and in favor of the neural footprint of conscious being in the back.

This provoked an intense backlash in the form of this letter, where it was claimed the theory is untestable, which I think is just baloney. And then, of course, there was blowback against the blowback, because people said, wait, IIT may be wrong—the theory is certainly very different from the dominant ideology—but it's certainly a scientific theory; it makes some very precise predictions.

But it has a different metaphysics. And people don't like this.

Most people today believe that if you can simulate something, that's all you need to do. If a computer can simulate the human brain, then of course [the simulation is] going to be conscious. And LLMs—sooner or later [in the functionalist view] they're going to be

conscious—it's just a question of, is it conscious today, or do you need some more clever algorithm?

IIT says, no, it's not about simulating; it's not about doing—it's ultimately about *being*, and for that, really, you have to look at the hardware in order to say whether it's conscious or not.

Does IIT involve a commitment to panpsychism?

It's not panpsychism. Panpsychism says, “this table is conscious” or “this fork is conscious.” Panpsychism says, fundamentally, everything is imbued with both physical properties as well as mental properties. So an atom has both mental and physical properties.

IIT says, no, that's certainly not true. Only things that have causal power upon themselves [are conscious]—this table doesn't have any causal power upon itself; it just doesn't do anything, it just sits there.

But it shares some intuitions [with panpsychism]—in particular, that consciousness is on a gradient, and that maybe even a comparatively simple system, like a bacterium—already a bacterium contains a billion proteins, [there's] immense causal interaction—it may well be that this little bacterium feels a little bit like *something*. Nothing like us, or even the consciousness of a dog. And when it dies, let's say, when you're given antibiotics and its membrane dissolves, then it doesn't feel like anything anymore.

A scientific theory has to rest on its predictive power. And if the predictive power says, yes, consciousness is much wider than we think—it's not only us and maybe the great apes; maybe it's throughout the animal kingdom, maybe throughout the tree of life—well, then, so be it.

Toward the end of the book, you write, “I decide, not my neurons.” I can’t help thinking that that’s two ways of saying the same thing—on the macro level it’s “me,” but on the micro level, it’s my neurons. Or am I missing something?

Yeah, it’s a subtle difference. What truly exists for itself is your consciousness. When you’re unconscious, as in a deep sleep on anesthesia, you don’t exist for yourself anymore, and you’re unable to make any decisions. And so what truly exists is consciousness, and that’s where the true action happens.

I actually see you on the screen, there are lights in the image; inside my brain, I can assure you, there are no lights, it’s totally dark. My brain is just in a goo. So it’s not my brain that sees; it’s consciousness that sees. It’s not my brain that makes a decision, it’s my consciousness that makes a decision. They’re not the same.

For as long as we’ve had computers, people have argued about whether the brain is an information processor of some kind. You’ve argued that it isn’t. From that perspective, I’m guessing you don’t think large language models have causal powers.

Correct. In fact, I can pretty confidently make the following statement: There’s no Turing test for consciousness, according to IIT, because it’s not about a function; it’s all about this causal structure. So you actually have to look at the CPU or the chip—whatever does the computation. You have to look at that level: What’s the causal power?

Now you can of course simulate perfectly well a human brain doing everything a human brain can do—there’s no problem conceptually, at least. And of course, a computer simulation will one day say, “I’m conscious,” like many large language models do, unless they have guardrails where they explicitly tell you “Oh no, I’m just an LLM—I’m not conscious,” because they don’t want to scare the public. But that’s all simulation; that’s not actually being conscious. Just like you can simulate a rainstorm, but it never gets wet inside the computer, funnily enough, even though it simulated a rainstorm. You can solve Einstein’s equation of

You can simulate a rainstorm, but it never gets wet inside the computer.

general relativity for a black hole, but you never have to be afraid that you’re going to be sucked into your computer simulation. Why not? If it really computes gravity, then shouldn’t space-time bend around my computer and suck me, and the computer, in? No, because it’s a simulation.

That’s the difference between the real and the simulated. The simulated doesn’t have the same causal powers as the real.

So unless you build a machine in the image of a human brain—let’s say using neuromorphic engineering, possibly using quantum computers—with that, you can get human-level consciousness. If you just build them like we build them right now, where one transistor talks to two or three other transistors—that’s radically different from the connectivity of the human brain—you’ll never get consciousness. So I can confidently say that although LLMs very soon will be able to do everything we can do, and probably faster and better than we can do, they will never be conscious.

So in this view, it’s not “like anything” to be a large language model, whereas it might be like something to be a mouse or a lizard, for example?

Correct. It is like something to be a mouse. It’s not like anything to be an LLM—although the LLM is vastly more intelligent, in any technical sense, than the mouse.

Yet somewhat ironically, the LLM can say “Hello there, I’m conscious,” which the mouse cannot do.

That’s why it’s so seductive, because it can speak to us, and express itself very eloquently. But it’s a gigantic vampire—it sucks up all of human creativity, throws it into its network, and then spits it out again. There’s no one home there. It doesn’t feel like anything to be an LLM. ☹️

DAN FALK (@danfalk) is a science journalist and broadcaster based in Toronto. His books include *The Science of Shakespeare* and *In Search of Time*.



When Kids Talk to Machines

Language bots are no substitute for teaching children to speak and learn

BY JULIE SEDIVY

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O LEARN LANGUAGE—to enter that doorway into collective human intelligence—children need conversation. *Lots* of it.

Until recently, people have been the sole source of their linguistic interaction. Now kids talk to machines. When Siri or Alexa were introduced into households, children began talking to them about science, the weather, and their favorite Disney princesses. Technology has found a home in the classroom, too. Many educators use tools powered by artificial intelligence, such as interactive games that engage kids in math and reading.

It's not hard to imagine a future in which a parent tucks a child in at bedtime with an app that not only reads a story but draws the child into gentle back-and-forth conversation about it. Or a kindergarten teacher who, instead of herding a gaggle of kids into a circle on the rug, sets each child up with a tablet that teaches the lesson in a way that responds to the child's own vocabulary size, level of English proficiency, and attention span.

As children's language environment changes, new questions arise. Like so much in our society, language is not equitably distributed. Affluent parents tend to have more time to talk with children for the sake of talking, and they can better afford higher quality childcare. Decades of research have shown that many children from lower socioeconomic backgrounds are less likely to be steeped in richly varied and interactive language.

These differences are consequential. Children's language development is dependent on their environment, and in turn, the language skills of children entering kindergarten, as measured by vocabulary size and grammatical complexity, are predictive of their later academic achievement.¹

Nationwide, teachers are burned out and quitting the profession they once loved. But schools in high-poverty areas have far greater trouble attracting and retaining teachers than schools in affluent neighborhoods. For some teachers stretched to the breaking point, an artificial teaching assistant may seem like their best hope for giving their students the help they need.

But does language generated by a bot find the same fertile soil in a child's mind as language produced by another person? The answer is far from obvious. It hinges on the fact that children's learning is strikingly

Children have a superpower that large language models lack.

different from how chatbots learn. The essential difference is that while chatbots are built to learn entirely from linguistic data, children are built to learn from people who use language.

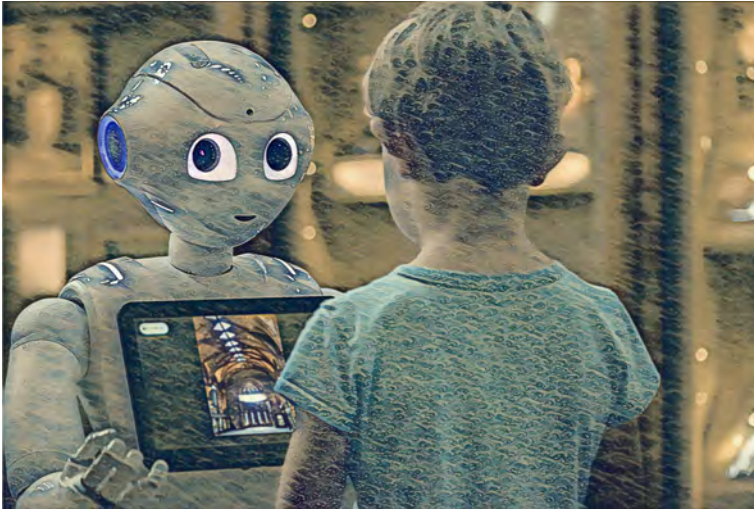
LARGE LANGUAGE MODELS

(LLMs) such as those that power ChatGPT are purely aggregate learners—they need to ingest breathtaking quantities of data to discern the statistical patterns that underlie language. Children, too, are capable of statistical learning. Experiments with simple artificial languages show that even babies can infer certain patterns merely by hearing disembodied streams of language.

But children have a superpower that LLMs lack. From its beginnings, children's language learning is social, embedded in close relationships with people who are motivated to teach them. This amplifies the efficiency with which children learn.² (The amount of input that children need is four to five orders of magnitude less than that used to train ChatGPT-3.) People use language with intentionality, striving to align thoughts with each other, and the youngest of children appreciate this in a profound way. As egocentric as young children are, they don't make the mistake of assuming that when someone utters a word or a sentence, they are expressing the child's thoughts rather than their own.

In a much-cited experiment, toddlers between 16 and 19 months of age were given a toy to play with while another object was slipped into a bucket, hidden from the child's view.³ While the child was gazing at the toy, an adult would say, "It's a modi!" Rather than assume that the word applied to the toy that was in the child's focus of attention at the time the word was uttered, the typical child would lock onto the adult's gaze, which was fixed on the thing in the bucket, and apply the word to that object instead.

The babies understood that the speaker had a *purpose*—to draw their attention to something that had caught the adult's notice. When later asked to identify the "modi," they more often chose the object that had been in the bucket, suggesting they had retained a connection between the word and this object.



WANNA BE FRIENDS?

Kids don't have an adult-like understanding of artificial agents. Some evidence suggests they are likely to anthropomorphize robots and attribute mental states to them.

When there's no obvious communicative intent—if a disembodied voice intones a word over a speaker while a child is gazing at an object—the child is disinclined to map the word onto the object. Mere correlation is not sufficient; the child wants positive evidence of a desire to align minds. In this regard, intelligent machines may be ambiguous even when they are embodied. One study reported that while children could follow the gaze of a robot, they failed to learn the name the robot offered for the object it was “looking” at.⁴

It's not hard to see how the ability to detect a speaker's communicative intent would make language learning much more efficient. It allows children to narrow the beam of their attention and ignore the many spurious correlations that occur between world and language, something that an AI currently has to work out through brute computational force.

But there are risks to this intensely social form of learning. Some speakers are unreliable; they may be mistaken or outright deceptive. If much of your reality is based on the words and behavior of others rather than on what you've seen or heard yourself, it would be wise to apply some sort of filter.

As eager as children are to learn from the articulate adults around them, they bring a dash of healthy skepticism to the process. They're less likely to accept a new word or a new fact if the speaker has made an obvious error earlier, like calling an apple a “dog.” They hesitate

to learn from a speaker who expresses uncertainty by saying, “Hmm, I've never seen one of these before. *I think* it's called a blick.” And they're more likely to learn from a familiar teacher than one they've never met before.

In short, rather than just sponging up all the language around them, they size up the speaker.⁵ *Can I trust this person to be competent?* The more authoritative the speaker, whether signaled by their age, confidence, even the complexity of their sentences or how they dress, the more readily the child learns from them. Evidence that the speaker belongs to the same social tribe as the child—belonging to the same race, speaking with the same accent, or even having been arbitrarily assigned to the same color-aproned “team” as the child—increases the child's willingness to learn from them.

The highly selective nature of trust in human teachers has been observed in babies as young as 18 months, and it grows in sophistication with age. As children's own knowledge deepens, they learn that a speaker might be knowledgeable about some things but not others and calibrate their trust accordingly.

It's possible that some of the endless questioning of young children is not just a bid for attention, but a way of probing the limits of other minds. My own niece, at the age of 3, took a very direct approach: When presented with a new fact, she often countered with the question “How do you know?”

WHAT HAPPENS WHEN CHILDREN interact with an artificial mind that *sounds* human, but whose competence or benevolence they can't possibly assess in any accurate manner? Language bots don't have mental states or emotions, but they talk as if they do because such language is rampant in the input on which they've been trained. There's a fundamental disconnect between their language and their internal states. Unable to distinguish true statements from false ones, current LLMs are terrible at discerning and reporting their own levels of uncertainty. How is a child to gauge the abilities or intentions of such an entity?

Some AI tools are currently being developed with the recognition that children need interactivity rather than merely ambient language. StoryBuddy, developed by language and technology scholar Ying Xu and her colleagues, is a bot that narrates books to children while engaging them in a dialogue about a character's motivations or the next likely step in the plot. Recently, Xu's team has used ChatGPT-4 to develop a tool called Mathemyths, in which children learn simple mathematical concepts by making up a story in collaboration with the bot.

But our understanding of children's interactions with AI is in its early days and lags behind the development of the technology itself. Much of the research has been done with less sophisticated versions of voice assistants such as Siri or Alexa, or with "social" robots that work off scripts; almost no work has been done yet on how children respond to more complex conversational agents powered by LLMs.

It's clear from the research, however, that children do not have an adult-like understanding of artificial agents in general. Some evidence suggests that young children are especially likely to anthropomorphize robots and attribute mental states to them.⁶ Perceiving them to be human-like (thinking that the robot can see or can be tickled) in fact enhances learning—as does the agent's responding to the child's conversational moves in ways that a human might.⁷

This leads us into an ethical thicket. Children are likely to learn from an AI if they can form a bond of trust with it, but at the same time, they need to be protected from its unreliability and its lack of caring instincts. They may need to learn—perhaps through intensive AI-literacy training in schools—to treat a bot

Like so much in our society, language is not equitably distributed.

as if it were a helpful human, while retaining awareness that it is not, a mind-splitting feat that is hard enough for many adults, let alone preschoolers.

This paradox suggests there's no easy fix to the language equity problem in the child's younger years—I doubt any reasonable educator would suggest to careworn parents that they simply hand over a phone to their toddler and let her converse with a voiced version of ChatGPT.

And to make carefully tuned educational AIs is no small task. Mathemyths, the bot that teaches math concepts through cooperative story-building, was created through a painstaking process in which researchers generated detailed prompts to steer the behavior of the LLM and repeatedly tested whether these prompts worked as intended, an undertaking that can be slow and expensive.

Even so, its creators caution, "It remains a challenge to provide precise directives to control the output specifically," and, like so many other "directed" AI programs, the model sometimes veered away from its instructions after extended conversations. It occasionally came up with nonsensical story elements that might seem scientifically sound to a child, such as using clouds to speed up travel, but offer incorrect information or principles.

Mark Warschauer and his colleagues are leading researchers in the design of AI-driven educational tools for young children, having developed several conversational agents that engage children in dialogues over narrated stories or educational videos. They report promising results. When 3- to 6-year-old children answered questions posed by a bot during the reading of a story, their comprehension of the story was as good as if they chatted with a parent about it—and in both cases, better than if they simply heard the story without any interaction. The Mathemyths bot, tested

Learning language is social, embedded in relationships with people.

with 4- to 8-year-olds, also showed that children were able to learn simple mathematical concepts as effectively as with a human interlocutor. (In both cases, though, children were more verbose when interacting with a human.)

These evaluations, however, were tightly constrained to compare like with like. In these studies, the human in the task either followed a script or received training to emulate the AI's behavior so that the linguistic content of the interactions was similar in both cases. This isn't unreasonable from a methodological standpoint, but it doesn't give the full picture of the things a human might do that can't easily be replicated by an AI. It's at best incomplete to compare children's interactions with machines to their interactions with humans who are behaving like machines.

A real person—particularly one who knows the child well—is likely to use language for purposes other than commenting on the story or checking the child's understanding of concepts. An attuned parent reading to their child might link the story to the child's own experiences, have a discussion about right versus wrong, or express delight at an unexpected plot twist or a pleasurable turn of phrase. They might also respond to a child's growing boredom or restlessness by ratcheting up the drama of the reading or redirecting the child's attention with pointed questions. These second-nature human behaviors likely serve the double purpose of deepening the bond between parent and child *and* heightening any learning that takes place.

I spoke with Roberta Golinkoff, a researcher at the University of Delaware who studies language development and the promise and limits of what is known as EdTech. She noted that such tools could usefully augment the linguistic input a child receives at home or school. However, she made a point of saying—with great emphasis—"I would *never* suggest that these tools should ever *replace* human interaction, only supplement them."

THE USE OF AI in education at any age will need to take into account how and why human connection is such an accelerant for learning, a phenomenon that has recently gained the attention of scientists, but remains poorly understood.⁸ There is increasing evidence that experiencing something in the presence of others has the effect of cognitively amplifying it—for example, tasting chocolate together with another person was found to intensify its flavor and viewing the same image as another person made it seem more appealing and realistic (but only if the two people already knew each other). We humans seem to derive great benefit from yoking our attention and actions with other humans, and this type of synchrony is unlikely to be replicated by AI.

There's a mystical flavor to expressions like "being on the same wavelength" or "vibing" with someone, but these experiences are very real as far as neuroscience is concerned.

Researchers have brought EEG machines into high school classrooms to record students' brain activity. They found that the degree to which students' brains were synchronized with each other⁹ was related to their sense of engagement with the material being taught, their feelings of closeness to their peers, as well as with their ability to retain the material.¹⁰ Interestingly, eye contact between students before class resulted in greater synchronization of their brains during class.

Amid the AI hype, it's crucial to remember that humans do not learn as machines do; it's not just the availability of information that counts, but the social context in which that information is experienced—a fact that helps to explain the disappointing learning outcomes associated with MOOCs (massive open online courses), which suffered from low student engagement and persistently high dropout rates, especially in less affluent countries.

Warschauer and his associates are now working to develop educational tools that bring parents into the

conversation to fill in AI's shortcomings. One project, intended for use by bilingual families, has centered around a conversational agent in the guise of Rosita, a *Sesame Street* character of Mexican ethnicity. Rosita narrates a story in either English or Spanish, and she can respond to either language or even a mix of both in the same sentence. In addition to asking questions that center on the narrative, she offers "family questions" that serve as prompts for parents and children to launch into conversations in which they connect elements of the story to the family's own life.

The goal is to relieve parents of some of the cognitive load of the interaction by guiding the child through an understanding of the story and reinforcing new vocabulary, while also creating a space for parents and children to engage in a more intimate way than would be possible if the child were speaking to Rosita on their own.

This approach aligns precisely with the recommendations of the Office of Educational Technology, a division of the United States Department of Education. In a report published in 2023, the authors write, "We envision a technology-enhanced future more like an electric bike and less like robot vacuums. On an electric bike, the human is fully aware and fully in control, but their burden is less, and their effort is multiplied by a complementary technological enhancement."

But most EdTech products—especially those that can be had for free—fall short of this ideal. If current trends continue, affluent households and schools will have access to the best AI tools for kids and students. But less affluent communities may have to make do with cheaper tech tools that promise much but deliver little. Rather than shoring up children's language skills, such tools will only discourage interaction with the forms of intelligence that they learn best from—people they can trust. ☺

JULIE SEDIVY is a language scientist who has taught at Brown University and the University of Calgary. She is the author of *Memory Speaks: On Losing and Reclaiming Language and Self*. Her latest book, *Linguaphile: A Life of Language Love*, will be released in October 2024.

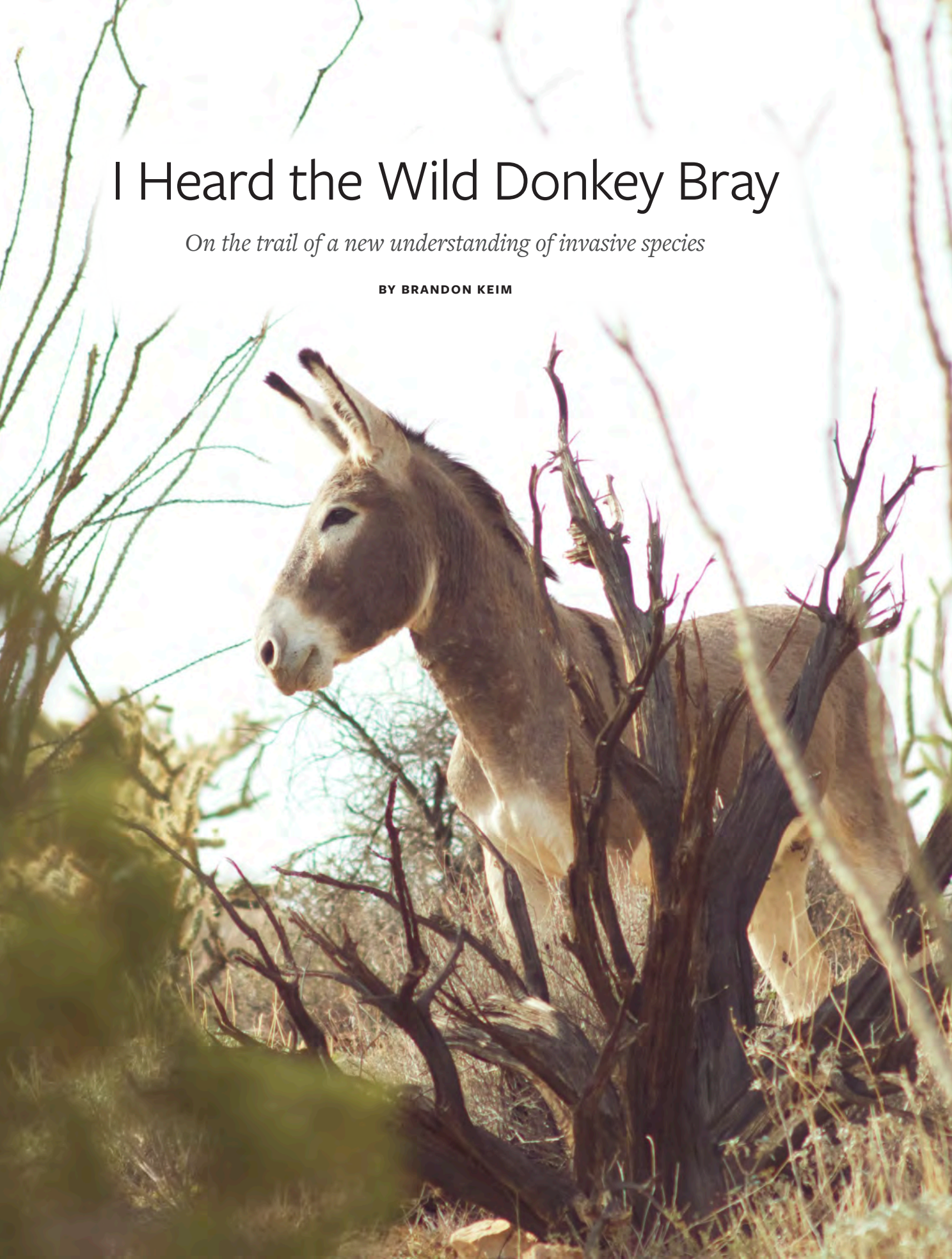
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I Heard the Wild Donkey Bray

On the trail of a new understanding of invasive species

BY BRANDON KEIM





TEN YEARS AGO, while camping in the Sonoran Desert, Erick Lundgren noticed something unusual: clusters of holes, several feet across and at least that deep, dug in a dry riverbed. Water pooled at the bottom. The holes were wells, dug by burros—better known as donkeys, but still called by their Spanish name in the American Southwest. They fascinated Lundgren.

In an otherwise parched landscape, the wells were unexpected oases. He wondered what other creatures might drink from them.

Lundgren, who at the time was a young biologist doing grunt work as a field technician on conservation projects, looked in the scientific literature for accounts of donkey-dug wells. He found none, which was not surprising. In their native East Africa, donkeys are critically endangered, with fewer than 600 remaining. There are hardly any to study. And in places like the United States Southwest, where donkey populations are descended from animals imported centuries ago to toil for Spanish colonists, most ecologists and conservation biologists—as well as land agency officials and wildlife managers and ranchers—generally considered them a scourge: invasive, destructive animals despoiling delicate ecosystems ill-adapted to their alien presence, overpopulated, in desperate need of eradication. Their hole-digging didn't deserve attention.

They “do not play a functional role in our existing North American ecosystems,” declares The Wildlife Society in a statement emblematic of the conventional wisdom. They're an invasive species and thus, “among the most widespread and serious threats to the integrity of native wildlife populations.” Lundgren, however, was not someone to accept convention on faith.

That had not always been the case. As a nature-loving kid and then a conservation biology-loving teen, he had learned that native species are good and nonnative species—those present because, at some point in history, humans moved them outside their previous range—are suspect. Whereas natives had evolved together into an intricately tangled community of life, nonnatives were interlopers; their ecological relationships tended to be fewer, poorer, and less life-sustaining. Some, freed from whatever checks and balances existed in their original homes, were destructive. These qualified as invasive. Killing them to protect ecological health was justifiable, even necessary.

One day, though, as he told his father about the dangers of Amur honeysuckle, an east Asian shrub now widespread in the eastern U.S., his dad said something

that made Lundgren pause. “I wonder what they will become?” he asked, meaning: What ecological relationships might, with time and evolutionary pressure, form around these newcomers? That resonated with Lundgren. It exemplified the curiosity and open-mindedness he believed a biologist should have. Soon he came to think that the dichotomy between native and nonnative species was far messier than he had been taught.

Before moving to Arizona, Lundgren worked on an island off the coast of California where cats were being exterminated to protect endangered native birds and to reduce competition with foxes. (The foxes had, in fact, been introduced to the islands by precolonial peoples roughly 6,000 years ago—long enough ago to escape nonnative designation and also to become a distinct subspecies.) When the contents of their stomachs were

LANDSCAPE ENGINEERS Donkeys not only selectively browse plants and distribute their seeds but also shape the very ground of the land where they live. Wells they dig in the desert become miniature oases in the parched landscape.



That's the sound of the Pleistocene.

examined, though, the cats turned out to subsist almost entirely on mice, while foxes were much more likely to eat the endangered birds. On another of these islands, conservationists had eradicated nonnative pigs—but the island's resident pig-deprived golden eagles started eating foxes instead, necessitating the capture of the eagles.

The tensions and ambiguities Lundgren encountered are more common than one might think. In Micronesia, for example, purportedly nonnative monitor lizards were long targeted for eradication, but they proved to be a native species that reached the islands thousands of years before humans. In Mongolia, genetic studies of endangered Przewalski's horses treasured as the last truly wild horses found them to be descendants of domesticated animals. Does it make sense to justify the killing of ostensibly nonnative mountain goats in Grand Teton National Park when, a few dozen miles away, they are accepted as native? And might nonnative species sometimes provide benefits to biodiversity, enriching webs of life in ways that a focus on nativity had ignored?

Lundgren had worked on a project in Hawaii, where native birds have been decimated by mosquito-borne malaria. In many forests nonnative birds now fulfill the ecological roles of their native counterparts, spreading seeds from which future forests will grow—yet the birds were killed as a matter of policy. Closer to home, in the Southwest, nonnative tamarisk trees were blamed for crowding out native riparian forests and the birds who lived in them, but tamarisks were simply better-adapted than natives to survive drought and human-caused water scarcity. Endangered southwestern willow flycatchers now depended on them.

Moreover, beyond his misgivings with newly murky rationales for killing some animals to help others,

Lundgren was troubled by how it was done. It wasn't that he couldn't stomach death; he'd grown up hunting. But this sort of killing was so casual and dispassionate, as if being labeled invasive exempted those creatures from even the barest regard. "If life doesn't matter, what the hell is conservation about?" Lundgren told me. Attempts at talking to his colleagues about this were met with stares.

By the time Lundgren decided to enroll in graduate school to study the interactions of native and nonnative species, these tensions had made their way into conservation discourse. "The practical value of the native-versus-alien species dichotomy in conservation is declining, and even becoming counterproductive," wrote scientists in a landmark 2011 article entitled, "Don't judge species on their origins." This remains far from a universal sentiment, but it was now part of the conversation.

Simultaneously, the nascent compassionate conservation movement argued that the value of individual animal lives, and the ethical frameworks developed to make sense of how people treated captive and domestic animals, deserved a place in conversations about wild animals as well. Lundgren was a receptive audience for this, too, and it fed his discontent with reflexive nativism.

Though Lundgren's graduate work started with seemingly esoteric studies of nonnative grasses, the question animating him was profound: What might people learn if they set aside preconceived notions about nativity and nonnativity and if they looked with clear eyes at what these species actually did?

He was, in short, the perfect person to notice the donkey wells.

THIS IS HOW WE ENDED UP in Cattail Spring, about 140 miles northwest of Phoenix, the last few of which were traveled over a dirt track rendered nearly impassable by washouts during the rainy season. Cattail Spring is not a town but simply a place in the desert where water sometimes flows, and there Lundgren had placed trail cameras—the first of these he purchased with a crowdfunding campaign on IndieGoGo, underscoring how unconventional the research was—in the hopes of documenting donkey well life.

We arrived in late afternoon and made camp. As night fell, we talked about his frustrations with the dogmas of nativeness. He asked how I felt about eradications of introduced rodents on islands where they prey on seabird colonies. These are probably the most clear-cut cases of nonnative species having calamitous impacts on biodiversity, in which my own unease at killing some animals to protect others is overcome by an appreciation of those teeming colonies and the offshore reef ecosystems nourished by their feces. “That’s the question I have a hard time with,” he said. “Eradication on continents”—where populations are not neatly contained, and immigrating animals can quickly replace those who are killed—“I think is total bullshit. But islands are tough.”

For my own part, I wish the killing of those rats and mice were at least accompanied by a sense of what environmental ethicist Chelsea Batavia and ecologist Arian Wallach, a prominent compassionate conservationist who was Lundgren’s Ph.D. adviser, called “the moral residue of conservation.” It’s not the rodents’ fault that humans so heedlessly moved their ancestors around the globe; their appetite for seabird chicks would, if expressed by an acceptably native animal, be treated as an inevitable part of nature. To kill them, even for noble purposes, is to take innocent lives. “Conservationists should be emotionally responsive to the ethical terrain they traverse,” argued Batavia and Wallach in the journal *Conservation Biology*. “Feelings of grief are commensurate with acts of harm. Apathy or indifference is not.”

In all my years of reading and writing about the killing of invasive species, I’ve yet to encounter an expression of grief. To Batavia and Wallach, this is troubling because those feelings “act as tethers to abiding notions of what is good and of value in the world.” To turn them off—Lundgren recalled a colleague who



MISSING BEASTS Until about 12,000 years ago, the North American Southwest was home to a plethora of large animals—camels, tapir, and mammoths. Today such beasts are largely missing. Could the wild donkeys be restoring some ancient services to this long-empty landscape?

To think of landscapes lacking
these animals as intact is a sort
of ecological amnesia.





THE LONG VIEW Ecologist Erick Lundgren has been thinking about how evolution is often disregarded in conversations about invasive species. He was inspired by his father, who once asked him, of an invasive plant, “I wonder what they will become?”

cried after euthanizing a native bird with a broken wing but killed nonnative birds with barely a change in expression—risks harming something important in ourselves. Callousness can only be maintained at the cost of compassion.

Lundgren agreed with this. A casual attitude toward killing introduced species, he added, also made it easy to avoid less tractable but equally important problems, such as the overfishing that is now starving many seabirds. Moreover, even on islands, the impacts of nonnative species could be nuanced: An analysis of 300 Mediterranean islands containing both seabirds and invasive rats found that rats limited the abundance of only one seabird species, something the researchers called “an amazing conservation paradox.”

“We don’t give any credit to evolution,” Lundgren said. Perhaps, over time, newly introduced and long-native species would surprise us with their ability to coexist. Perhaps in many places they already were coexisting—but the ease of killing so-called invasives, and the habits of mind that reinforced, made it hard to

see. I fell asleep to such thoughts beneath a starscape that, in the dry desert air and the absence of human habitation for miles in every direction, was as clear as any I’d ever seen.

At some indeterminate point in the night we were awakened by a nearby donkey’s braying, a sound that is easily lampooned—*hee-haw!*—but in that place was nothing less than majestic. Proud, even, anthropomorphism be damned, and fiercely independent.

At daybreak we found hoofprints: A group of donkeys had gathered a few hundred feet from our cots. Perhaps they had been curious about our presence; perhaps the bray was someone’s way of letting us know that this was their home. From a ridgeline we sipped coffee and watched the sun rise, bathing the valley below in the gentle glow that precedes the crucible of day. There were no donkeys in sight but their distant brays echoed off canyon walls and mingled with coyotes howling their night’s end.

“That’s the sound of the Pleistocene,” said Lundgren. By this he meant that until about 12,000 years

ago—the end of the geological epoch more conversationally known as the Ice Age—the region was inhabited by a whole menagerie of large-bodied animals, among them camels, tapir, mammoths, and two species of wild horses, including one with an uncanny resemblance to donkeys. Like most of North America's large animals, they were extirpated or driven extinct by a combination of climate change and human hunting.

Where megafauna still survive in their native ranges, though, they're considered landscape engineers and keystone species whose ecological functions are uniquely tied to their size.

Research on them abounds: They disperse seeds across vast distances, distribute enormous quantities of nutrients in their dung and eventually their corpses, and create landscape-replenishing vegetative mosaics with their grazing. Through a long historical lens, then, their absence in the modern Southwest is both an aberration and a loss. To think of landscapes lacking them as being intact is a sort of ecological amnesia.

To Lundgren, the automatic perception of donkeys in terms of damage and alien origin reflects a failure to appreciate what megafauna do and a blindness to how conservation's idealized baselines are actually missing an entire guild of creatures. They're not identical to horses who once lived here, but their presence is far less strange than their absence. Lundgren identified a creosote bush for me. Creosote reproduces both through seeds and by cloning themselves; the oldest known colony is estimated to be nearly 12,000 years old. "It was one of the first plants to arrive at the end of the Ice Age," he said. "It germinated with mammoths and camels around it, but it's still here."

AFTER LOADING OUR PACKS, we set off for the springs. Our footsteps crunched on the rocky, mostly bare soil, though it was hardly barren.

The Sonoran Desert is one of the more biodiverse deserts on Earth, and as my northeastern eyes recognized few of the plants, Lundgren helpfully identified them for me: Crossosoma, prosaically known as ragged rockflower. Ocotillo, also called coachwhip, covered in spines that hinted at an evolutionary history of being eaten by large herbivores. A small

yellow palo verde tree that had a very recent history of being eaten.

"Look at what burros did to this plant!" Lundgren exclaimed. They had somehow reached into branches that stretched well above our own heads and pulled them down, snapping them off the trunk. "How do you interpret that?" he continued. "It's hard for that plant—but that's what herbivores do. It's unique, though. Nothing native is doing this now. But they used to do things like that."

A few of the breaks were fresh; others, weathered. We were not looking at a single episode of feeding but instead many spread across the years, shaping the tree's growth and, Lundgren suspects, effectively pruning the tree and stimulating the growth of tender new shoots that might be consumed by such animals as bighorn sheep.

"The question is, how do you approach this?" said Lundgren. "What lens do you take? There are slides from Arizona Game and Fish"—the state's wildlife management agency—"that show images like this. The argument goes that native herbivores don't have front incisors, but wild donkeys do. Therefore plants die. Which I think is kind of magical thinking. Plus they're not dying. They're getting browsed."

Even so, I countered, wouldn't these trees be more vulnerable to disease? Every browsed tree might not die, but more would than in the absence of donkeys. "Totally. That's possible," Lundgren answered. "But what does that mean? Is that good or bad? I have a hard time if a system changes from having topsoil to having no topsoil. But shifting the species composition? Or shifting the architecture of trees? Those are not clear-cut good and bad, I don't think." ☺

BRANDON KEIM is a freelance journalist and contributing editor at *Nautilus*. His new book, *Meet the Neighbors*, explores what the science of animal intelligence means for how we understand and live with the wild creatures around us.

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A Scientist Walks Into a Bar ...

How comedy plays on our emotions to fight misinformation

BY SARAH ADELMAN

IT SOUNDS LIKE THE SETUP to a joke: When I was starting out as a stand-up comedian, I was also working as a research scientist at a sperm bank.

My lab was investigating the causes of infertility in young men, and part of my job was to run the clinical visits with the participants. They would provide a semen sample for research purposes in exchange for \$75.

But a common point of concern quickly emerged among the participants: Many were worried that female scientists, such as myself, would want to steal their semen samples and bear their offspring without consent. My initial strategy to quell their paranoia was to trot out the standard science lines, explaining that it would not only be unethical, but also illegal, to use their biospecimens outside the bounds of pure research.

This did not seem to work. So I decided to try out my new side hustle on them:

“Oh please,” I’d say. “Most women won’t fight over sperm that came from a guy who happened to have three hours of free time in the middle of a workday. I could get Ivy League-Olympian sperm from any sperm bank in the country. Don’t flatter yourself.”

Exposing the irrationality of their fear with such irreverence and getting a laugh seemed to be the only thing that calmed down anxious participants.

Since those first interactions at my sperm lab, I’ve been employing humor as a way to cut through the noise in science communication to reach people more quickly and effectively—especially when emotions run high and misinformation flows freely.

Decades’ worth of study have demonstrated that humor has the potential to enhance most forms of communication. Research shows that laughter increases people’s energy, interest, and approval of topics, both big and small. During the panic over toilet paper in the early days of the COVID-19 pandemic, the Taiwanese government started a “Humor Over Rumor” campaign. In one effort, they published a popular meme with a cartoon of the then-Taiwanese Premier Su Tseng-chang waving his behind with the caption “We only have one butt!” According to anthropologist Jacob Tischer at Boston University, the campaign was effective in reducing stockpiling.

One 2018 study assessed whether humor would be able to change attitudes toward MMR (measles, mumps, and rubella) inoculation among participants who were vaccine-hesitant. Participants were randomly assigned to read text excerpts from *The Daily Show with Jon Stewart*, some with jokes or others with

Humor seems to work by flipping some of the same emotional switches that misinformation uses.

the humor edited-out.¹ One example of the text riffed off a news clip where an anchor called measles “off-the-chain contagious”:

Funny example: This just in, measles is off-the-chain contagious! (Singing) It likes big lungs and it cannot lie! I guess what she’s trying to say is measles started from the bottom, now it’s here. Obviously I’m not a doctor. Pardon my ignorance. But what does the medical establishment mean by “off-the-chain contagious”?

Normal example: As you can see, measles is something we need to be concerned about again. Obviously I’m not a doctor, just a news reporter. Pardon my ignorance in infectious diseases. But what does the medical establishment mean by “off-the-chain contagious”? Let’s see what they have to say in this next clip.

The researchers found that the humorous example, while containing the same factual information, was not only more effective at reducing MMR vaccine hesitancy among participants compared to the example that didn’t contain humor, but it was also able to reduce participants’ negative psychological reactions—such as anger and irritation—toward the topic.

Humor can also be an effective way to combat misinformation surrounding more existential scientific topics such as climate change. A different 2018 study examined responses to a satirical video from *The Onion* titled “Climate Change Researcher Describes Challenge of Pulling Off Worldwide Global Warming Conspiracy.”² In it, a fictional scientist reports that:

I could get Ivy League-Olympian sperm from any sperm bank in the country. Don't flatter yourself.

Getting every single scientist in the entire world to propagate a lie that human activity can *cause* global warming is a colossal undertaking ... The legwork on this has been truly astounding. You don't even wanna know how much planning has gone into making sure the Great Barrier Reef looks like sh*t.

The study found that climate-skeptical participants who watched the video were later more likely to believe that climate change was real and to have an increased perception of climate change's risks. This effect was strongest among the participants who were the most skeptical of climate change to begin with.

Humor seems to work, in large part, by flipping some of the same emotional switches that misinformation uses. A comical approach can pull people to override their logical and critical thinking.³ But researchers often shy away from humor, perhaps because comedy and hard science often seem to live at opposite ends of the spectrum. Humor swings wildly for the most outlandish fences, while science is hemmed in by strict specificity and perceived seriousness.

When I first started using humor to enhance my work as a scientist, I was also doubtful that I could still be taken seriously. Sara Yeo, a communications professor at the University of Utah, is familiar with that hesitation. "Science is seen as a neat, serious, somewhat sterile process," she says. "Humor is at odds with this perception." However, Yeo asserts that if used adroitly, humor can blend well with serious scientific findings. A review found that a solid humorous approach can almost always enhance science communication—and does not reduce trustworthiness of the scientist.⁴

"There always needs to be some kind of balance [in science communication]," argues John Cook, a senior research fellow at the Melbourne Centre for Behaviour Change at the University of Melbourne. "You don't want to be all doom and gloom because that can

paralyze, but you don't want to just give hopeful and humorous solutions, because then people lack urgency. You need both. You need to say here's a problem—but we can solve it."

Sometimes, science humor succeeds by tapping into emotional reasoning, a cognitive distortion in which our logical reasoning is overpowered when we feel a strong emotional response.⁵ (This is why love can be blind, or why we say things in arguments we regret later; the heart has a tremendous ability to override the brain.)

One comedy technique, known as a parallel argument, uses emotional reasoning to combat compelling misinformation—in a twist—by forcing more logical thinking. The author will create a flawed narrative in an over-the-top context. I used a version of the parallel argument with the nervous young men at the sperm bank: By comparing their samples to those from a Princeton alum Olympian, I was able to counteract their fear by highlighting their irrationality.

John Cook makes hay with this approach in his illustrated book *Cranky Uncle vs. Climate Change: How to Understand and Respond to Climate Science Deniers*. One illustration features a man bundled up in the winter outdoors, saying, "It's cold ... global warming doesn't exist!" Beneath it, a similar illustration shows the same man outdoors at night, saying, "It's dark ... the sun doesn't exist!" By pointing out a logical flaw in an absurd way, Cook leverages humor to fact-check climate change misinformation. In case studies, Cook and his collaborators have found that a spinoff Cranky Uncle video game successfully helped students identify misinformation and encouraged critical thinking. "Humor was an effective way to build people's resilience against being misled," he says.

Even when dealing with heavy topics like the global climate crisis, "humor is disarming," Cook says. "You can bring people in—but then also give them enough

People are conditioned to stick around to wait for the punchline.

information to properly understand the threat.” This is in part because people are conditioned to stick around to wait for the punchline. “When you start telling a joke, people then have the expectation there’s going to be a payoff at the end of this journey. They stay with you because they know they’re going to be rewarded. So, it’s a way to hold people’s attention, and you get more cognitive effort from them.” And a potentially wider opening in which to share accurate information.

Supporting that conclusion, a 2021 study found that humorous parallel arguments outperformed non-humor approaches in correcting misinformation about the HPV vaccine.⁶ According to participants in the study, the humorous corrections actually seemed more credible than the straightforward, just-the-facts versions.

One big challenge in applying humor to serious scientific topics is that jokes tend to elicit strong emotional responses, and sometimes those responses can backfire. “Knowing who is in the audience is especially crucial—how can one make jokes that do not alienate or make members of the audience feel targeted?” Yeo says. But sticking with the stereotypical, no-nonsense scientific attitude comes with its own perils. “We know from decades of research that delivering information alone is not sufficient to change attitudes and behaviors,” she adds.

You know, sometimes it just takes a chicken and a road—or a crushing joke about your genetic fitness—to get the point across. 😊

SARAH ADELMAN is a former research scientist and holds her B.A. from Dartmouth College and M.P.H. from Columbia University. She is a stand-up comedian, writer, and a creative consultant at Hello SciCom where she helps scientists be more entertaining. You can find out more about Sarah at www.sarahadelmancomedy.com.

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Falling in Love with a Fly

My Octopus Teacher's *Craig Foster* considers the uncharismatic

BY CRAIG FOSTER

IT'S ONE THING TO FALL IN LOVE with creatures we consider regal, clever, or sweet, but what about those we've learned to swat away? I've never liked flies, especially after an encounter years earlier on the great Gariep River, which stretches from South Africa into Namibia. At the time I had begun experimenting with creating land art, which I'd felt drawn to after seeing the work of Andy Goldsworthy. I struggled greatly at first before managing to find my own simple style—placing natural objects like bones, stones, shells, and kelp in patterns on the ground and then photographing them in the landscape.

Not long after I'd arrived in the area, millions of tiny flies that had recently reproduced were congregating in giant swarms. Most of the other people fled the area until the swarms passed, but I was committed to venturing out, desperate to do my art. I was bitten everywhere, and no amount of waving a branch over my head helped.

Eventually I tied a mosquito net over my head. Still, it was very hard to tolerate the swarms, which sometimes dimmed the sun. The only positive was that I had the entire wild landscape to myself.

And so I couldn't imagine loving a fly. But that all changed when I got a glimpse inside their lives. It first started when Jannes Landschoff, my marine biologist friend and colleague, and I were out one afternoon and I noticed strange little tracks on bare granite rock in the upper intertidal zone of the ocean, the area that gets wet at high tide only. I asked Jannes about these tracks, which looked like little white squiggles, and he thought they might be traces of salt left in the cracks. We kept walking, and then I saw them again.

By that point, I'd been focused heavily on tracking and my eyes were keyed to pattern recognition. Something told me these weren't random salt traces. Jannes and I got down on our hands and knees and looked up close.

There we found strange little leathery casings that had attracted tiny particles of sand. Suddenly Jannes gasped. "Oh my God," he said. "It's larvae."

Totally hidden on what looked like rock around us were hundreds of animals. We had no idea what they were because they were still in larval stage.

"A beetle, maybe?" Jannes wondered.

The larva turns into a liquid, and somehow that liquid knows how to make a creature that can fly.

I had no idea. We sent the pictures to University of Cape Town professor Charles Griffiths, who had become my trusted mentor in all things marine biology. He thought it was the larvae of a marine fly.

“Marine insects are rather rare,” he added. “Please try to find the creature that hatches once the larvae transform, as it could be new to science!”

This is what I love about tracking: I get to become a nature detective.

So every day I kept returning to the same spot. With my friend and collaborator Pippa Ehrlich’s help, I found empty casings where the animal had hatched—and she found one rather strange looking fly still attached to its cocoon with its wings all curled and folded up.

I waited for movement, but there was none that day. I did discover many of the larvae were actually underwater in shallow pools—this truly was a marine insect.

It was when I began to do further research on this humble fly’s life cycle that I discovered something fascinating. The flies lay eggs, which then hatch into larvae. These larvae are eating machines, the great composters of nature, turning dead matter into nutrients. But the really interesting part is when the creature has reached the end of its larval cycle but before it becomes an adult fly. I’ve always thought the larva somehow grows wings and legs and transforms that way, but what happens is very different.

The larva first turns into a liquid, and somehow that liquid knows how to make a creature that can defy gravity and fly. Out of the liquid, the atoms rearrange themselves to produce a perfect little flying machine.

If you gave a bunch of our best scientists a billion dollars they’d be hard-pressed to make a fly from scratch.

Nature is priceless.

A week later Jannes and I set out to find our mystery fly. It was midwinter, the wind was freezing, and I was not confident about our chances. We searched everywhere, and just as we were about to give up, in the last pool we found one perfect fly resting on kelp. I had a few seconds to set my camera to macro and take a few images before the wind blew the fly away.

How does an animal made of material softer than paper survive and thrive in a place that is so hostile to something so small—where huge waves thrash against rocks, temperatures fluctuate wildly, and predators abound?

After just a week of tracking that long-legged silvery fly, I glimpsed its magnificence and its magic.

I’d thought it impossible, but I’d fallen in love with a fly. ☺

CRAIG FOSTER is a documentary filmmaker and founder of the Sea Change Project, a nonprofit environmental storytelling organization. His *My Octopus Teacher* won the Academy Award for Best Documentary Feature in 2021.

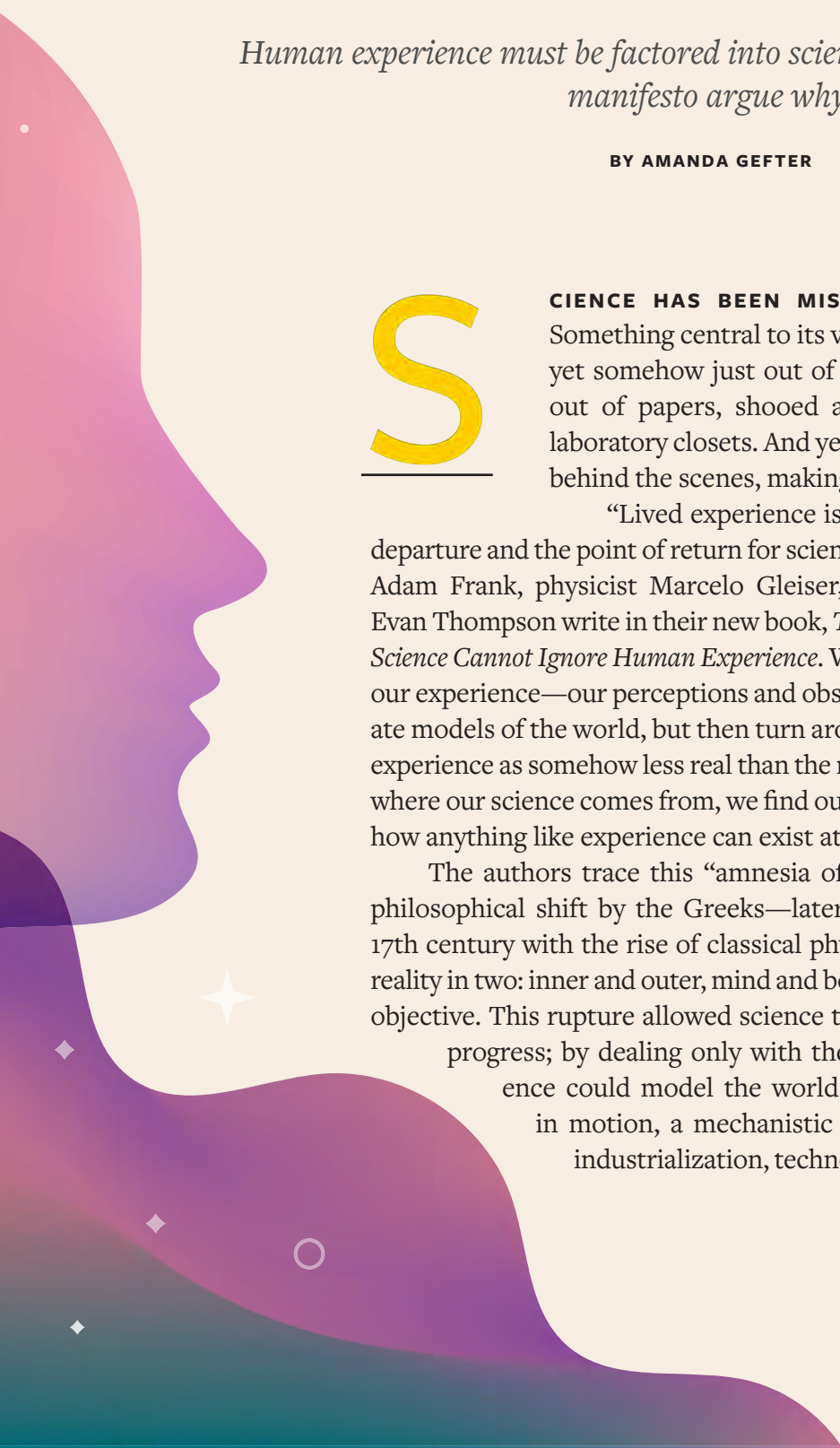
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What Science Forgets

Human experience must be factored into science. The authors of a new manifesto argue why.

BY AMANDA GEFTER



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SCIENCE HAS BEEN MISSING something. Something central to its very existence, and yet somehow just out of view. It is written out of papers, shooed away, shoved into laboratory closets. And yet, it's always there, behind the scenes, making science possible.

“Lived experience is both the point of departure and the point of return for science,” astrophysicist Adam Frank, physicist Marcelo Gleiser, and philosopher Evan Thompson write in their new book, *The Blind Spot: Why Science Cannot Ignore Human Experience*. We use the fruits of our experience—our perceptions and observations—to create models of the world, but then turn around and treat our experience as somehow less real than the models. Forgetting where our science comes from, we find ourselves wondering how anything like experience can exist at all.

The authors trace this “amnesia of experience” to a philosophical shift by the Greeks—later cemented in the 17th century with the rise of classical physics—which split reality in two: inner and outer, mind and body, subjective and objective. This rupture allowed science to make enormous progress; by dealing only with the second half, science could model the world as simple matter in motion, a mechanistic view that birthed industrialization, technology, modern life.

That left the first half hanging—so scientists chalked it up to illusion or epiphenomenon; they tucked it away into our collective blind spot.

In vision, it's what's *in* the blind spot (the optic nerve) that allows us to see. And the same, the authors argue, is true in science: It's experience that allows science to function. It's a fact we better remember, they urge, before it's too late.

Today's major conceptual difficulties—the unruly multiverse, the hard problem of consciousness—as well as existential dangers—artificial intelligence, climate change—are, the authors argue, the result of ignoring the blind spot for too long.

The Blind Spot is a controversial book—a manifesto, really—one that seeks to overturn centuries-old philosophical assumptions that are commonly mistaken for science itself. I spoke with all three authors together over Zoom: Frank, a professor of physics and astronomy at the University of Rochester; Gleiser, director of the Institute for Cross-Disciplinary Engagement at Dartmouth College; and Thompson, a philosophy professor at the University of British Columbia. We talked about the social nature of consciousness, the impossibility of Boltzmann brains, and the trouble with taking a God's-eye view of the universe.

*Everything we
do starts with
our experience of
being in the world.*

What is the blind spot?

Marcelo Gleiser: Modern science began by looking at how things moved in the skies, and that was easy to do through a mechanistic, objective way of thinking about the world. That success gave us excessive confidence that we can take this God's-eye vision of the world, rationalize everything, and forget about the most fundamental thing of all: that everything we do in life, and in science, starts with our experience of *being* in the world. When we take ideas too far away from where they originated in experience, we get lost.

Evan Thompson: Take the example of temperature. We start with bodily sensations of hot and cold. Then we progressively abstract and idealize until we arrive at thermodynamics. And there's nothing wrong with that—that's essential for the development of science. The problem is when we forget. We substitute mathematical models for the concrete phenomena themselves. The blind spot is that amnesia of experience.

Whether we're talking about measurements in quantum mechanics, the experience of time and duration, or the investigation of living systems, there's always an experiential source and motivation that, at the end of the day, has to be readdressed in order for the science to be valid and meaningful.

What goes wrong when we forget about experience and try to take this God's-eye view of reality?

Adam Frank: We see it with the multiverse. There's this enormous extrapolation that has already gone into the theory of cosmic inflation. It originally was a great idea, but then it turns out, well, the fields that

we wanted for the inflaton—the proposed mechanism behind cosmic inflation—they don't really work. Then there's more and more abstraction until the inflaton field isn't really connected to anything, you're just making it up. And then *that* long series of abstractions leads to the conclusion, "oh, there's got to be an infinite number of unobservable universes!"

By reifying abstractions, you're getting so far away from the grounding in lived experience that you're willing to accept ideas that can't even be validated scientifically.

Gleiser: They're beyond experience.

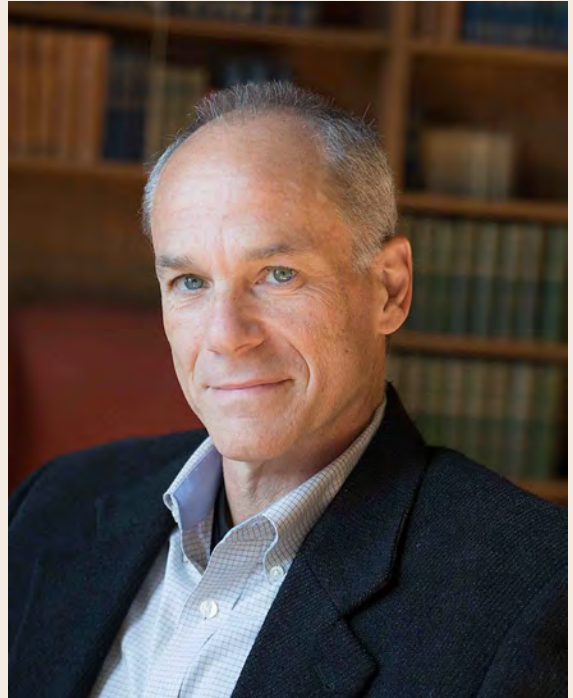
Frank: You have to return to experience. Especially when you get into trouble like that.

I think when most people hear the word "experience," they think of something that happens inside of them—inside their heads. But of course that idea of experience—as something totally internal and individualistic—is rooted in the same 17th-century ideas that the blind spot you're talking about came from. So what I want to ask is: What is experience, where is experience, and who does it belong to?

Thompson: Experience for us is always social and intersubjective—and we criticize views of consciousness that make it impossible to understand experience in that way.

For example, there's work in the neuroscience of consciousness that leads people to say things like, "reality is a controlled hallucination that arises from a predictive coding model in the brain." If you take that statement literally and follow its logic through, then the brain you think you're observing is just content inside the model in the head of some individual, and you have no right to the notion of the physical brain that you're helping yourselves to. And you can't account for science as a collective enterprise, because then it would be everybody somehow in their own solipsistic universe managing to communicate outside in predictive coding terms, that just doesn't make any sense as a theory of how the mind works. It's another reification.

Experience is something that is shared; it has a history and a culture behind it. And a body for that matter. A living body.



THE PHYSICIST Marcelo Gleiser, of Dartmouth College's Institute for Cross-Disciplinary Engagement, points out that when we start playing around with concepts like infinity, we can forget how important it is to stay rooted in reality.

In an infinite universe there is a finite probability of anything—an orchid could appear here next to me.

Frank: A body, right. There was one day at Lindisfarne—the intellectual community that Evan’s father founded, where people went to do really radical thinking—and Gregory Bateson, the cyberneticist, was talking with Jonas Salk. Bateson asked Salk, “Where is your mind?” And Salk, being a good reductionist, pointed to his head and said, “Up here.” And Bateson said, “No, no, no”—and motioned around and between them. And he didn’t mean panpsychism. He meant that mind is the interaction.

I would say the entire biosphere is implicated in your experience, you can’t separate out. There are no brains in vats. There are no Boltzmann brains that magically appear. Experience implicates everything, every aspect of life, the entire history of life. It’s a very different way of thinking. The philosopher William James had this idea of “pure experience.” That’s what we want people to focus on. It’s so close that it’s easy to miss. And in our scientific culture, we’ve pushed it away, but it’s what’s given every day when you wake up.

You mentioned Boltzmann brains—hypothetical free-floating brains that spontaneously appear, complete with all the perceptions and memories needed to trick it into thinking it’s an ordinary observer in an ordinary universe. It seems like a perfect example of every one of these blind spot mistakes being made all at the same time. First you assume that a lone, disembodied brain can have experiences, and then you use the existence of those Boltzmann brains to try to define probabilities in an infinite multiverse—by determining the chances you are most likely a Boltzmann brain.

Frank: I’m sure I’m going to offend somebody, and I apologize, but I wanted to write a paper on Boltzmann brains called, “The Dumbest Idea

in Physics.” It assumes that experience can happen in this brain in a vat that just spontaneously appears, and then you’re going to use that in some theoretical physics framework to decide which kinds of universes are going to have observers in them ... it’s an incredible chain of mistakes.

Gleiser: Those mistakes are rooted in the reification of infinity. Infinity is not something that we can ever confirm exists in reality. If you say the universe is infinite in space, how can you *know* that? You’d have to travel infinitely far away. You could say, “Well, the measurements tell you that the geometry of the universe is close to being flat.” Awesome. But you can’t go beyond “close to.” It could still be a very big sphere.

It’s the same for an infinity of time. People play these games with infinity as if it is something real. In an infinite universe there is a finite probability of you spontaneously generating anything—an orchid could appear here next to me, a Boltzmann brain ... I mean, poor Boltzmann. Of all people.

He had enough problems.

Gleiser: If I saw a Boltzmann brain materializing somewhere, then okay, I’d say there is something going on here. But, you know, as Bertrand Russell said, go find a teapot in orbit around the Earth.



THE ASTROPHYSICIST

Adam Frank, of the University of Rochester, suggests that if we bring ourselves back to experience, we won’t get so tangled in theoretical messes like multiverses.



THE PHILOSOPHER

Evan Thompson, of the University of British Columbia, notes that experience doesn't live in an isolated silo in our own heads—but rather is constructed externally and, perhaps even more importantly, is shared.

Frank: In the constellation of ideas that make up the blind spot, reduction is one of the big ones—but so is the kind of Platonism that replaces mathematics for the actual world. And I think probably Marcelo and I started that way. I mean, I don't want to speak for you, Marcelo.

Gleiser: I was a string theorist!

Frank: We're lapsed Platonists. I was like, "Oh my God, this is great: Spinoza's idea that the law of circles is to circles as God is to nature"—I had that Einsteinian vision, I was enraptured by it. But as time went on, I just came to see the lack there.

And just to pick up on Marcelo's point, it's not only infinity, it's infinitesimals, and infinite precision. In physics, we make a lot of arguments using phase space and coarse graining, where the idea that you could have infinite precision plays a role in making these blind spot mistakes.

Thompson: I often read statements like, "The universe is a physically deterministic system, and therefore, there can be no free will; free will is an illusion." That's a mistake that comes from substituting a model in which things can be stated to infinite precision for the universe itself, where infinite precision is never possible. These things really affect how people understand themselves as living persons in the world. When people are told, "Science says you don't have free will," they revolt against that, naturally. And that gets us into a bad situation of science denial, on one hand, and science triumphalism on the other, both arising out of a blind spot misrepresentation of science.

COURTESY OF EVAN THOMPSON

Frank: It's not *science's* blind spot. It's a blind spot in the philosophy of science that has been glued *onto* science. It's a metaphysics that we've been told for 200 years: *This is what science says*. Science says, "You don't have free will." Science says, "You are nothing but a meat computer." No, it doesn't. The *metaphysics* says those things. Science itself is this ongoing, creative, self-reinventing process. And that's what we're trying to cleave. We're really trying to show that distinction.

In your book, you have a quote from Newton where he describes an intelligent, omnipresent being who can apprehend all of infinite space at once. In other words, Newton invoked the perspective of God, standing outside the universe, looking at everything at once, as part of the formulation of classical physics. As physics developed, that literal figure of God dropped out of the story, but physics retained the God's-eye perspective and transformed it into the very notion of objectivity—which is supposed to be the thing that differentiates science from religion. What an interesting plot twist in the history of science! And it seems like it's especially relevant still in cosmology, where the universe is treated as a singular object, as if one could comprehend it from the outside. Does getting away from the blind spot require us to think differently about the universe?

Gleiser: When we talk about the universe as a "thing," we have to remember that we are inside that thing—like a fish in a bowl. Our current model has too many holes. I think a lot of them come from our limitations in trying to make sense of something that is much bigger than we are. The cosmic microwave background radiation, for example, does not make sense for scales as big as the universe as a whole. That's where all the error bars are.

From a mechanistic approach, to have a theory of the universe, you have to have an equation that describes the universe as a whole. That equation needs two things: an objective description of the system and an initial condition. But we can't have either. So the universe provides a clear way of qualifying what we mean by the ramifications of the blind spot.

It seems like the blind spot has been getting us into worlds of trouble. Is the climate crisis one manifestation?

Gleiser: We have to think of the history that brought us here. First, the blind spot in science convinced us that we can objectify the world, that the only value it has is as a pool of resources that we can use to supply the demand that we have in our project of civilization, and that there are no repercussions to our actions.

Second is the ideology of infinite progress, brought by corporate greed, which relies on mechanistic ways of thinking about the world that were part of Enlightenment rationality. It's the idea that we can rationalize our problems and solve them through science alone. "Oh, we're messing up? No problem, we'll just sequester carbon from the atmosphere or plant more trees!" That might help, but it's not going to solve the problem. For that we need to take a much deeper look at our belonging to the natural

We're trained that the third-person view is the only way to talk about the world, that anything else is “woo.”

world, which is connected to the experience of being alive. We have forgotten our bond to the world, and that's where Indigenous thinking and ancestrality can help us in ways which are not just materialistic but spiritual to reconnect to nature.

Frank: In the '90s, there was the whole social constructivist thing about science—which we're very much against—which was like, “Oh, science is just a plaything for the powerful. It's just a game with made-up rules.” No—the powerful adopted science because it was powerful. Because you can make better cannons. But the philosophy that went along with science, those in power took *that* on because it was useful. This “decentralized nature,” this nature that has nothing to do with us, is so deeply implicated in the industrial political economies—whether it's capitalism, socialism, or communism—that it became the only way to look at it.

Moving forward, to get us out of climate crisis, is going to require us to embrace some of these other perspectives that are coming out of science: network theory, information theory, complex systems—ideas that don't have blind spot metaphysics glued to them. What's really required is an entirely new conception of nature.

I'm struck by the way in which all these different concepts—the universe, mind, nature—lean on each other. You almost have to rethink them all simultaneously in order to understand what you're even talking about.

Thompson: That was one of the things that was very salient in working on this book—that all of these things are densely interconnected. It's not the kind of book that any one of us could have written. It took thinking together. The experience of writing the book wasn't in anyone's head. We all came with different bodies of knowledge, and we were all learning from

each other. There was no way that could have come about in a more classical, single-authored way.

We actually need to start thinking more in this way, in terms of relationality networks that include us as agents, as measurers, as abstractors. That's what it takes to work ourselves out of the blind spot.

Gleiser: It's a mindset, a worldview that we are presenting, and it affects everything we do creatively and in science.

How did the three of you end up working together?

Frank: Marcelo and I had been introduced by someone who knew we had similar views about science and religion. That is, we're both atheists. But we understood that there was still a problem with, as Marcelo put it, the God's-eye view, or what I think of as the third-person view.

I was aware of Evan's work. His dad, the social philosopher William Irwin Thompson was one of my heroes, so that connection meant something to me. For sabbatical, I was at the Institute for Cross-Disciplinary Engagement at Dartmouth College, where Marcelo is the director, and I suggested bringing Evan.

So Evan came for a few weeks, and our conversations just exploded. We all got along so well, and we recognized our mutual affinity for trying to work this out. Because it's very difficult! As scientists and philosophers, we're trained that this third-person view is the *only* way to talk about the world, that anything else is "woo." And so we had to try to maintain the rigor of clear reasoning, while also acknowledging that there is a limit to this third-person view, to what we call the blind spot.

We had these amazing conversations over tea, over dinner. I felt like if we'd all been 17 years old, we would have had the same passion arguing over our favorite bands—or we would have started one. That's why I still refer to us as "the band."

I think if it was a band, you wouldn't be having conversations over tea.

Gleiser: Well, there *was* chalk dust involved. 😊

AMANDA GEFTER is a science writer and the author of *Trespassing on Einstein's Lawn*.





The Oldest Ecosystems on Earth

How life persists through deep time

BY FERRIS JABR



WITHIN 10 MINUTES of entering the Hoh Rainforest in Washington State, I began to understand why this place was so beloved. As one of the largest old-growth temperate rainforests in the world, the Hoh did not merely look different than its younger neighbors—it *felt* different. Inside its borders, air seemed to stand still. Light took on a chlorophyllic hue. And the scent of wet earth and lush vegetation pooled around me.

Soon I was ensconced in enchanted groves and hal-
lowed hollows steeped in every possible shade of green
and so lavishly pillowed with moss that I could not
find a speck of bare bark. I encountered ancient bigleaf
maples whose contorted bodies formed living archways
and Douglas firs so wide and tall that I struggled to
capture their scale on camera. Doused in 12 to 14 feet
of rain every year, and long protected from logging, the
Hoh is home to trees that stand more than 200 feet tall
and have lived for centuries. Some pockets of the forest
possessed such a primeval atmosphere that they might
have been plucked from the Jurassic.

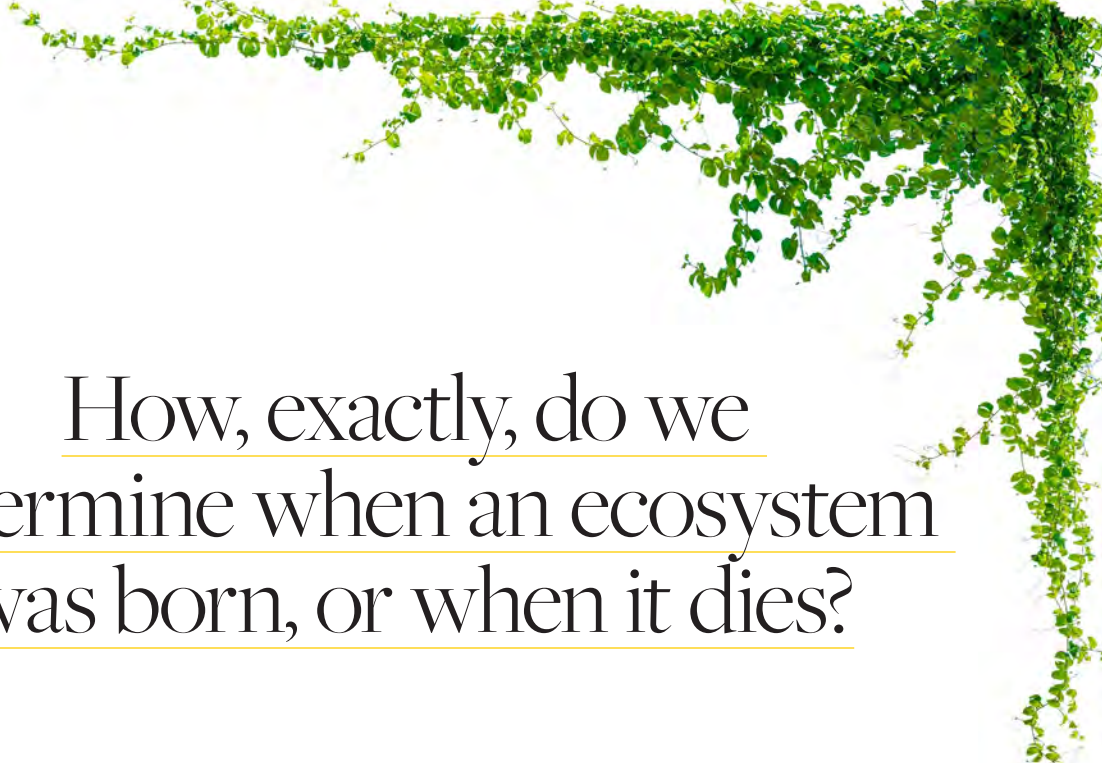
When it comes to biological superlatives, we typi-
cally focus on individuals: The largest tree in a for-
est, the oldest organism on the planet. After visit-
ing the Hoh Rainforest, however, I began to wonder
about superlative *communities*. What are the oldest
existing ecosystems on Earth, and what can we learn
from them?

Like the Hoh, some old-growth forests have sur-
vived for centuries. But it turns out that certain ecosys-
tems and biomes on the planet today have persisted for
hundreds of thousands to *tens of millions* of years, pre-
serving, somehow, their defining characteristics despite
undergoing major changes.

To make an analogy to a famous thought experi-
ment: If every component of a ship is gradually replaced
with a sufficiently similar replica, the vessel retains its
essential form, even though it is no longer identical to
its previous iteration. Similarly, most of the cells in our
bodies have died and been replaced many times over
since we were born, yet we still recognize the conti-
nuity of our overall anatomy. And some cities have
maintained a distinct topography, infrastructure, and
culture for millennia, even with a continual turnover of
buildings and inhabitants. The changes that ecosystems
endure through geologic time are even more dramatic,
but the principles are similar.

Precisely what it means for an entire living system
to be so old, and what makes such astonishing longev-
ity possible, remain open questions, in part because
they challenge our very notions of what it is to be
alive. When we adopt a deep time, holistic perspective,
some ecosystems take on an almost organismic quality,
shifting across the planet's surface like giant amoebae,
expanding and retreating in response to environmental
fluctuations, yet persisting as coherent entities.

Scientists have not yet agreed on a precise definition
of life, but many experts have phrased it more or less
like this: Life is a system that actively sustains itself.



How, exactly, do we determine when an ecosystem was born, or when it dies?

The laws of thermodynamics dictate that everything in the universe will inevitably fall apart, dissolving into a homogenous mush. Living systems use available energy to temporarily evade this outcome and maintain their improbably organized structures. More than genetics or reproduction, it is this capacity for self-preservation that unites life at every scale, from protist to prairie.

In this sense, ecosystems are very much alive. The feedbacks between ecosystems and the organisms within them, and their reciprocal evolution across great spans of time, culminate in an emergent capacity for extreme longevity that eclipses what is possible at the level of the individual. Although ecosystems are not organisms, they nevertheless demonstrate growth, resilience, and self-regulation.¹ Those systems best able to recover from major disturbances, and maintain the processes, relationships, and infrastructure that define them, will endure the longest. Ecosystems survive and evolve not through differential reproduction, but through differential persistence.

The tenacity of the planet's longest-lived ecosystems reveals an essential characteristic of life at any scale: interconnection. By definition, all living things are systems made of smaller interrelated parts. Those systems are themselves inextricable from the larger

networks that surround them. Every individual tree is a universe of mineral, water, and cell harboring sprawling communities of microbes and fungi. At the same time, a tree is a vital component of the larger forest, landscape, and even the very weather systems on which it depends.

In the Anthropocene, however, many of these fundamental relationships are now faltering. Some of these ancient ecosystems are being pushed to the brink of collapse—fracturing so thoroughly that they may effectively die.

ONE OF OUR PLANET'S OLDEST ECOSYSTEMS is a vast meadow currently about the size of Manhattan. You will never see any bees or butterflies flitting through it, however, nor can you nap in its greenery. The meadow in question grows along the seafloor between the Spanish islands of Ibiza and Formentera.² Like all meadows, it is composed primarily of plants, in this case seagrasses: a group of formerly terrestrial plants that returned to the sea nearly 100 million years ago and now inhabit sheltered waters around every continent except Antarctica.

In 2010, marine ecologist Sophie Arnaud-Haond and her colleagues swam through this underwater meadow, collecting genetic samples of Neptune grass (*Posidonia*



PLODDING PERSISTENCE In the sunlit shallows of the Mediterranean, an ancient meadow of Neptune grass (*Posidonia oceanica*) has slowly shifted and adapted to local changes in climate for tens of—and possibly hundreds of—thousands of years. But most previous changes have unfolded at a far slower pace than those humans are currently causing.

oceanica) from dozens of different sites. Like all seagrasses, Neptune grass can multiply by cloning itself. Within the meadow, the scientists found numerous clones, some as far as 9 miles apart. Given the grass' slow annual growth rate, they calculated that these clones must have been spreading through the region for somewhere between 80,000 and 200,000 years in order to form a meadow so large. They speculate that as global climate changed and sea level rose and fell, the meadow repeatedly shifted its range. At times, large swaths of it likely died due to unsuitable conditions. But presumably, a sufficient number of clones survived each climatic upheaval to continue their lineage to the present day.

Elsewhere in the ocean, there are even bigger and older ecosystems formed not by a single clonal species, but by symbiotic colonies of tiny gelatinous animals, photosynthetic plankton, and microbes. We call them coral reefs. Spanning 133,000 square miles, and visible from space, Australia's Great Barrier Reef is not only

POMMEYROL VINCENT / SHUTTERSTOCK



Wherever life emerges, it dramatically changes its environment.

the largest coral reef system in the world—it is often regarded as the largest living structure on Earth. Just as impressive is its age. Scientists think the Great Barrier Reef was born about 500,000 to 600,000 years ago and that it has survived—in one area or another—to the present day.

Scientists have revealed a similar long-term persistence of coral reefs in Papua New Guinea. And during particularly stable periods within the greater course of Earth history, there were reef systems that likely endured for several million years.

To form reefs, corals first need to attach to a rocky surface. When a reef suffers a calamity, such as a hurricane, the calcified remains of dead corals can become the foundation on which survivors build anew.

“Reefs are fascinating things,” says Gregory Webb, a paleontologist who has extensively studied reefs through geologic time. “The resilience of a community that can reform and regrow and do its thing, even when faced with severe disruption—it’s magic.”

In 2018, marine geoscientist Jody Webster and his colleagues published a landmark study reconstructing the past 30,000 years of the Great Barrier Reef’s evolution—a span of time entailing considerable climatic fluctuation.³ When sea level dropped, much of the reef was exposed and died. Conversely, when the seas swelled, large parts of the reef drowned in turbid water. In response, the Great Barrier Reef repeatedly and gradually migrated seaward or landward, maintaining its continuity through time.

Perhaps the oldest currently surviving ecosystems, however, are on land. Some tropical rainforests have likely persisted in the same general region with the

same essential characteristics for tens of millions of years. This is partly due to geography. In some respects, the equatorial zone has long been one of the more climatically stable parts of the planet, even as continents themselves have moved in and out of its bounds.

Based on detailed studies of climate records and fossils, paleobiologist Carlos Jaramillo and his colleagues have traced the origin of the modern tropical rainforest—defined as being perpetually warm and humid, multi-storied with closed canopies, and dominated by flowering plants, lianas, and epiphytes—to the beginning of the Cenozoic era, shortly after the asteroid impact that contributed to the demise of non-avian dinosaurs about 66 million years ago.⁴ By roughly 60 million years ago, with the continents in relatively similar configurations as today, the Americas had rainforests characterized by the same basic structural features and plant families as the ones that live there now. Given this type of evidence, Earth system scientist Mark Maslin and his colleagues have written that the Amazon rainforest has “prevailed relatively intact” as a “permanent feature of South America for at least the last 55 million years.”⁵

Scientists have unearthed a parallel story of rainforest longevity in Australia. “Many plant families that are now common in extant rainforests and form their basic structure and most of their diversity have had a consistent history on the Australian continent for the past 40 million years,” says Darren Crayn, a botanist and director of the Australian Tropical Herbarium. As he and his colleagues write in one study, “The endurance, survival, and persistence of these rainforest lineages provide one of the Earth’s greatest biological and evolutionary success stories.”



GOOD BONES One hallmark of long-lived ecosystems is self-preservation. Corals need rocky substrate on which to build their homes—which often end up being the calcified remains of dead corals.

PUTTING BOUNDS ON THESE AMORPHOUS, ancient entities is challenging. How, exactly, do we determine when an ecosystem—with all of its complexity and fungibility—was born, or when it dies?

The oldest ecosystems on the planet today are undoubtedly different from their earlier versions. Their borders, regional topography, and species composition have all shifted through the millennia. Although the fossil record is spotty, the Great Barrier Reef almost certainly had a different biodiversity profile 400,000 years ago, for example, including species that no longer exist. And the Amazon River—such a defining feature of

today's Amazon Rainforest—did not form until about 11 million years ago. Nevertheless, if we could travel back hundreds of thousands or millions of years, these ecosystems would be uncannily familiar because they have maintained their essential characteristics—the relationships and frameworks that define them—for an astoundingly long time.

To better understand such longevity, we must identify what underlies it. Seagrass meadows, coral reefs, and rainforests share several key qualities. They all inhabit the tropics, which tend to be less climatically volatile than more extreme latitudes. They are



all founded by organisms that are themselves highly resilient and adaptable. And, to some extent, they all create or reinforce the very conditions they need to survive. By slowing waves, trapping sediments, performing photosynthesis, filtering and oxygenating water, and sequestering carbon in their structures, both seagrass meadows and coral reefs make their environments calmer, clearer, less acidic, more nutrient-rich, and all around more habitable.⁶ Corals also produce more of the rocky substrate they need to grow.

Likewise, rainforests generate much of the rain on which they depend by dramatically accelerating the water cycle. Cloud formation relies on two essential ingredients: water vapor and particles on which that vapor can condense. Rainforests provide both by expelling huge volumes of water into the atmosphere, along with numerous tiny airborne particles, such as pollen

LAND BEFORE TIME The Amazon Rainforest might be the oldest surviving ecosystem on the planet. Scholars suggest it emerged—in a reasonably recognizable form—about 55 million years ago.



There is a kind of solace in looking at ecology through the lens of deep time.

grains, fungal spores, microbes, fragments of insect shells, and various organic compounds. The result is a self-reinforcing feedback loop: The more it rains, the more the forest grows; the more the forest grows, the more it rains. Scientists have calculated that the Amazon Rainforest generates about half of the rain that falls on its canopy each year.

The capacity of ecosystems to regulate and sustain themselves—to have some degree of agency in their own survival and evolution—is an echo of more self-contained living organisms. Scientists have made such analogies, and debated their validity, for more than a century.

In the early 1900s, American ecologist Frederic Clements proposed that forests and other botanical communities underwent a series of discrete developmental phases similar to those of individual organisms, maturing from a juvenile stage into a stable “climax community.” Eugene Odum, another 20th-century American ecologist, thought that ecosystems, like organisms, demonstrated homeostasis, the ability to maintain a

set of chemical and physical conditions essential for their survival. More recently, a cohort of scientists, including some who study coral reefs, have argued that every complex multicellular organism and its symbiotic microbes should be regarded as a community known as a holobiont—and that the true unit of natural selection is this community’s collective genetic information, the hologenome. In other words, a coral and its symbiotic partners are so interdependent that we should regard them as a cohesive evolving entity. By extension, one could make a similar argument about the entire coral reef ecosystem. Ideas like these remain highly controversial.

The extreme longevity of ecosystems underscores the importance of the bonds between such large-scale systems and their constituent organisms. Ecosystems may not have singular genomes or participate in standard Darwinian evolution, yet they are capable of growing, surviving, and evolving because they are inescapably intertwined with the growth, survival, and evolution of the organisms that comprise them.⁷

Wherever life emerges, it dramatically changes its environment. These changes inevitably influence any subsequent evolution within that environment. Given enough time and opportunity, this coevolution can contribute to an emergent capacity for persistence on the scale of hundreds of thousands to millions of years.

Yet even living systems as ancient and resilient as rainforests and reefs are neither impervious nor immortal. Most of the periods of climatic turmoil that the planet's extant ecosystems have survived so far unfolded much more gradually than the rate at which humans are polluting and transforming the air, land, and sea today. By the end of the century, warm-water coral reefs may be all but destroyed by global warming, reduced to fragmentary refugia. And the Amazon's self-reinforcing rain cycle is getting terrifyingly close to breaking.

Even faced with these dire possible outcomes, however, there is a kind of solace in looking at ecology through the lens of deep time and recognizing the remarkable tenacity of Earth's longest-lived communities. Humanity's power is outsized, but not infinite. As a whole, life's tendency is to endure and recover, discovering new forms over thousands to millions of years.

Toward the end of my hike on the Olympic Peninsula, after meandering along a riverbank bordered by giant ferns, I came upon a forest within a forest. One of the Hoh's giants had fallen, most likely decades earlier. Its colossal body, recumbent and fractured, had become the foundation for a new population. Here was both grave and nursery: a decaying trunk sheathed in moss and bristling with ferns and saplings. Its massive upturned root ball, 10 feet tall at least, was now the pedestal for a copse of young Douglas firs. By germinating in the remains of their elder, they had begun life high above the shady understory. Now, they glowed gold in the sun, the newest members of a persistent living collective. ☺

FERRIS JABR is a contributing writer for *The New York Times Magazine* and the author of *Becoming Earth: How Our Planet Came to Life*. He has also written for *The New Yorker*, *The Atlantic*, *Harper's*, *Outside*, *Wired*, and *National Geographic*. His work has thrice been anthologized in *The Best American Science and Nature Writing* series.

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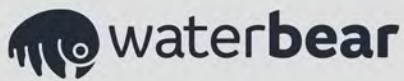
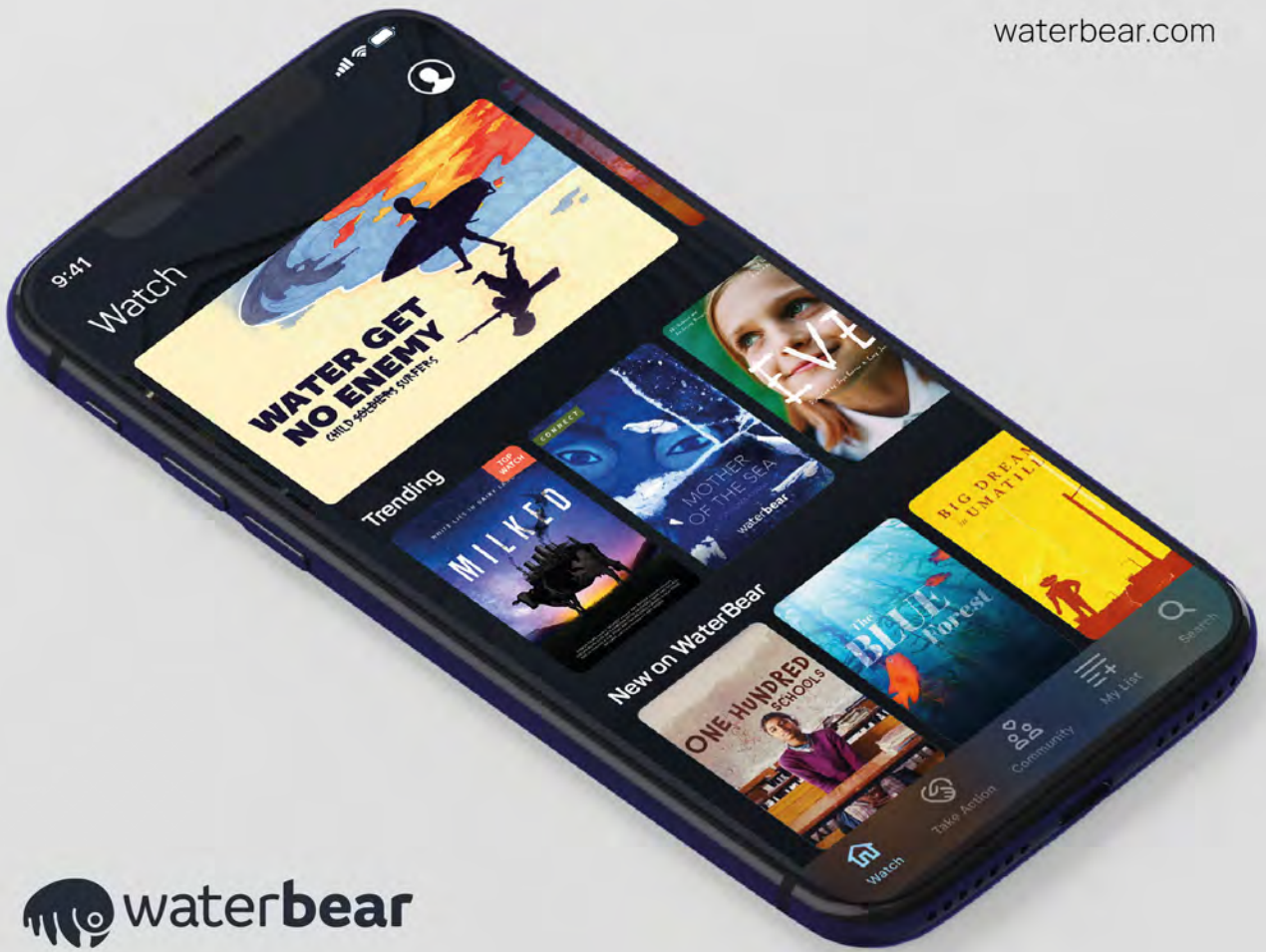
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GUIDE TO OUR REGULATORY SEASCAPE



MAKING HUMANS AQUATIC

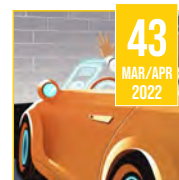


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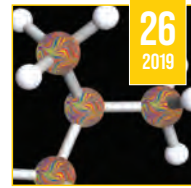
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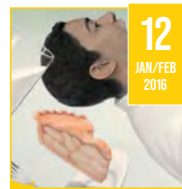
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Biodiversity Loss Is the Greatest Menace on Earth

Craig Foster on his 3 greatest revelations while writing his book, Amphibious Soul

BY CRAIG FOSTER



1

BIODIVERSITY IS THE SINGLE MOST PRECIOUS THING ON THIS PLANET

I've spent 12 years and 4,400 dives eye to eye with otters, crabs, octopus, cuttlefish, rock suckers, and many other exquisite creatures of the Great African Seaforest. I've learned directly from them and the underwater tracks they leave.

I know their secret lives, and I still have so much to learn. They have filled my intellect with a fundamental truth and woven it around my heart. They have taught me that the single most precious thing we will ever encounter in our lives is the vast collection of animals and plants that make up the millions of species on Earth, which in turn make up all the habitats and ecosystems on land and ocean. We call it biodiversity, but it's really the Mother of mothers, our life support system.

Of all the threats facing the Earth today, the loss of biodiversity is the biggest. We all know that as we lose the bacterial diversity in our guts, we get sick. As species biodiversity diminishes in response to climate change and industrial and technological expansion, the planet has been getting sick, too. Planetary biodiversity is the immune system of our Earth. She is losing the resilience required to cope with rapid changes. Even if we sequester all of the excess carbon from the atmosphere and clean up our environment, we will still face catastrophe if we can't halt biodiversity collapse.

Places of high biodiversity affect our minds and our entire beings in a profound and powerful way. They wake us up and give us hope and energy to experience life with joy and vitality. These places are the reservoirs of hope that have the potential to regenerate our natural world.

2

NATURE HEALS

Deep in our blood and bones is the biology of the human animal. Our wild psyches crave a relationship with nature—one of reciprocity and care—but this desire is smothered by modern cravings for material comforts and power. This is why I write in my latest book of the double life, the “Amphibious Soul”: We each have a wild soul hidden underneath our tame public personas. This magnificent wild soul knows how to respect the planet and live with it sustainably—but it has been repressed. We need to find a more equal balance.

In the process of writing this book and revisiting my many experiences in the wild, I can speak to how profoundly healing being in nature can be. In addition to the well documented physical benefits of cold-water immersion, other health benefits are being studied in detail by scientists. There is now no dispute that spending time in nature is beneficial for mind, body, and spirit. Today, in many countries around the world, doctors can actually prescribe time in nature as medicine. It's not just about a walk in the park or a swim in the ocean, but about paying attention to the wilderness around you: paying attention to the tree, knowing its leaves, the texture of its bark. It's about watching the animals and insects and birds that attend that tree, recognizing the patterns and prints of their presence. To pay attention like this is to learn the oldest language on Earth, the language of tracking. It's a language of freedom and play, connection and empathy.

3

INDIGENOUS WISDOM MUST HAVE A PLACE IN CONSERVATION PROGRAMS

Being in nature and making conscious connection to it is the bedrock of Indigenous wisdom. According to a rough estimate by the World Bank, Indigenous people protect 80 percent of the remaining biodiversity on the planet, and yet they constitute just 4 percent of the global population, and have suffered the most in terms of exploitation and marginalization. Their long history of success with biodiversity reveals how imperative it is that we place Indigenous wisdom at the center of all global discussions that affect policies and programs for healing our damaged biosphere. All of Earth's creatures will benefit. ☺

SEA BEYOND

From the ocean we have to the ocean we want

Sea Beyond is the educational programme promoted by the Prada Group and UNESCO's Intergovernmental Oceanographic Commission (IOC), to raise awareness on sustainability and ocean preservation. The programme recently extended its scope beyond education, with two new areas of focus related to the ocean: support for scientific research and humanitarian projects. Sea Beyond is funded by 1% of Prada Re-Nylon collection revenues.

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