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Bad Apple

NEWTON'S SURLY GENIUS p.26

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The New You

I'D BEEN TO A LOT of science and tech conferences, but it was clear right away that this fall's World Economic Forum meeting in Tianjin would be different.

For one thing, it took place in a cruise ship-sized convention center surrounded by a sea of empty concrete and flagpoles in coastal China. A couple of at-attention soldiers could be picked out in the distance, past a fleet of black Audis and through a yellow haze. Word was that the building had been commissioned with the Forum in mind.

Then there was the limelight. The Premier of China gave the opening keynote. There were lots of CEOs and foundation chairs, and the attending roster included Hillary Clinton (though she ended up bailing). This wasn't just science for scientists.

The context sharpened into view when, in the middle of a small session I was moderating, the founder and chairman of the Forum, Klaus Schwab, arrived to deliver a surprise speech. Technology decades ago, he told us, was important because it improved this or that aspect of our lives. Today, it is important because it is changing who we are.

This seemed simultaneously encouraging and alarming. Encouraging, because the centrality of science to our lives was being recognized at the highest levels. Alarming, for the questions it raised. Did we want to be changing ourselves? And who would decide?

Regardless, the changes are underway, and you'll read about many of them in this *Quarterly*: the reversal of our evolutionary trend to have children at younger ages, the genetic engineering of intelligence, and the blurring of the line between life and death, among others. As Schwab said, it is not just a new world out there—it's a new you.

Welcome to the winter 2015 *Nautilus Quarterly*.

—*Michael Segal*
Editor in Chief

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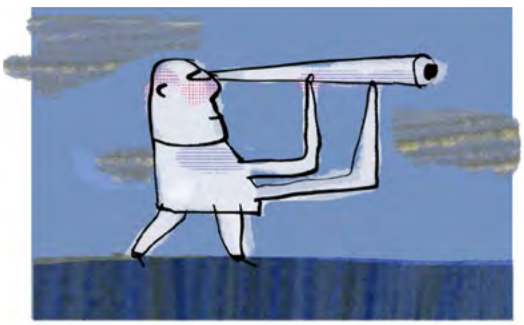
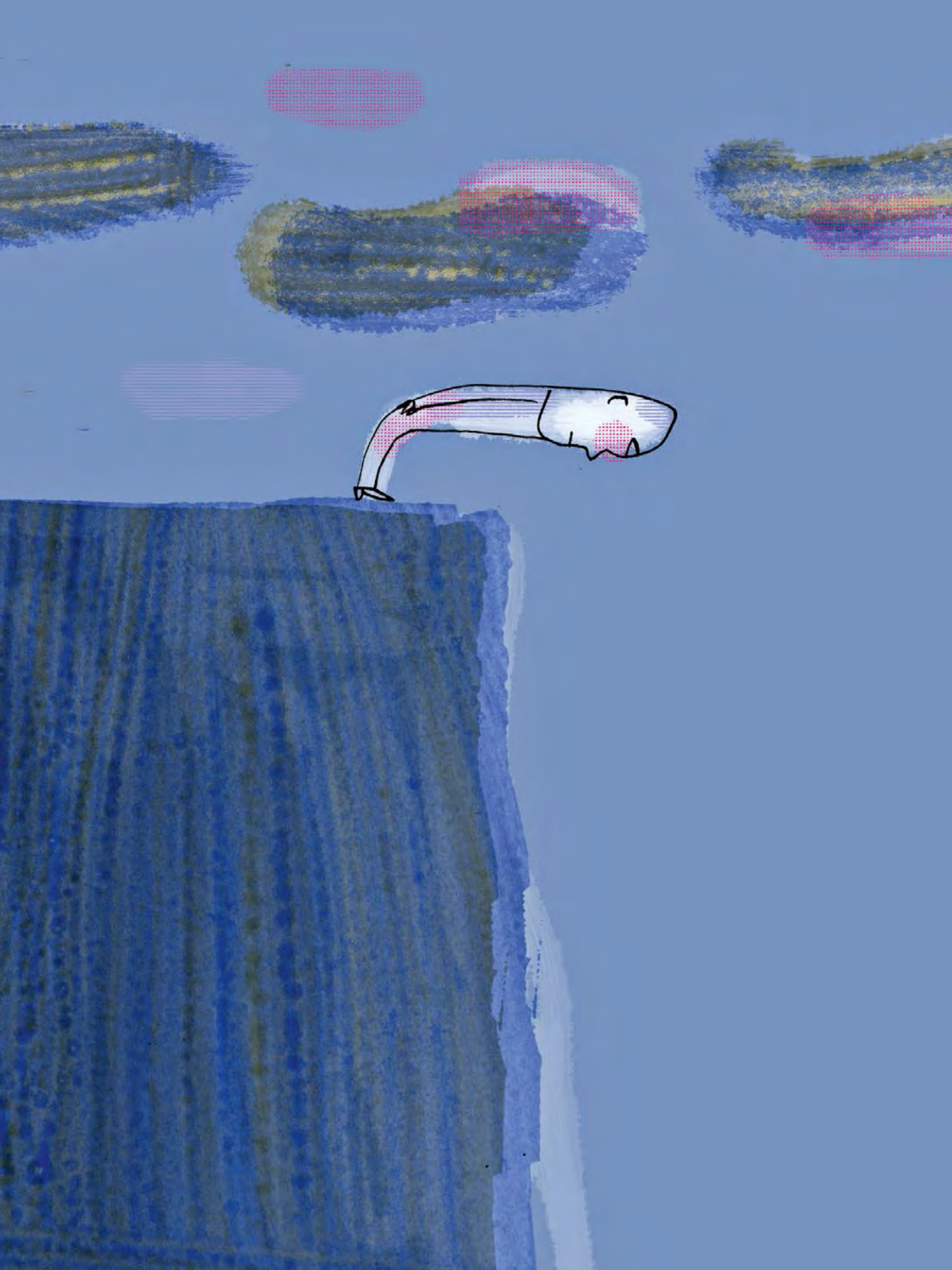


Nothingness

What lies beneath everything

THEME ART Serge Bloch



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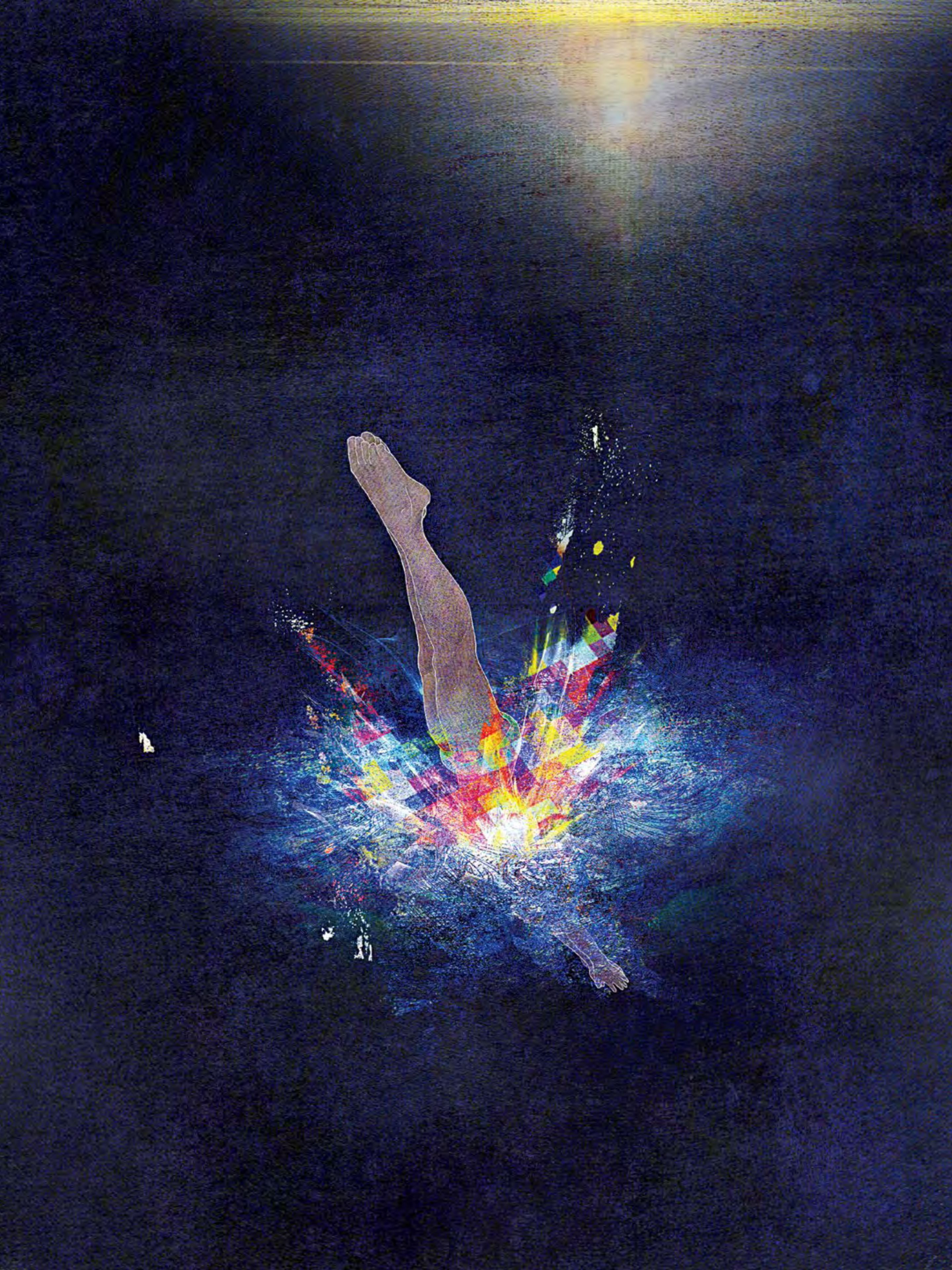
Big Bangs

So it begins

THEME ART Michael Woloschinow



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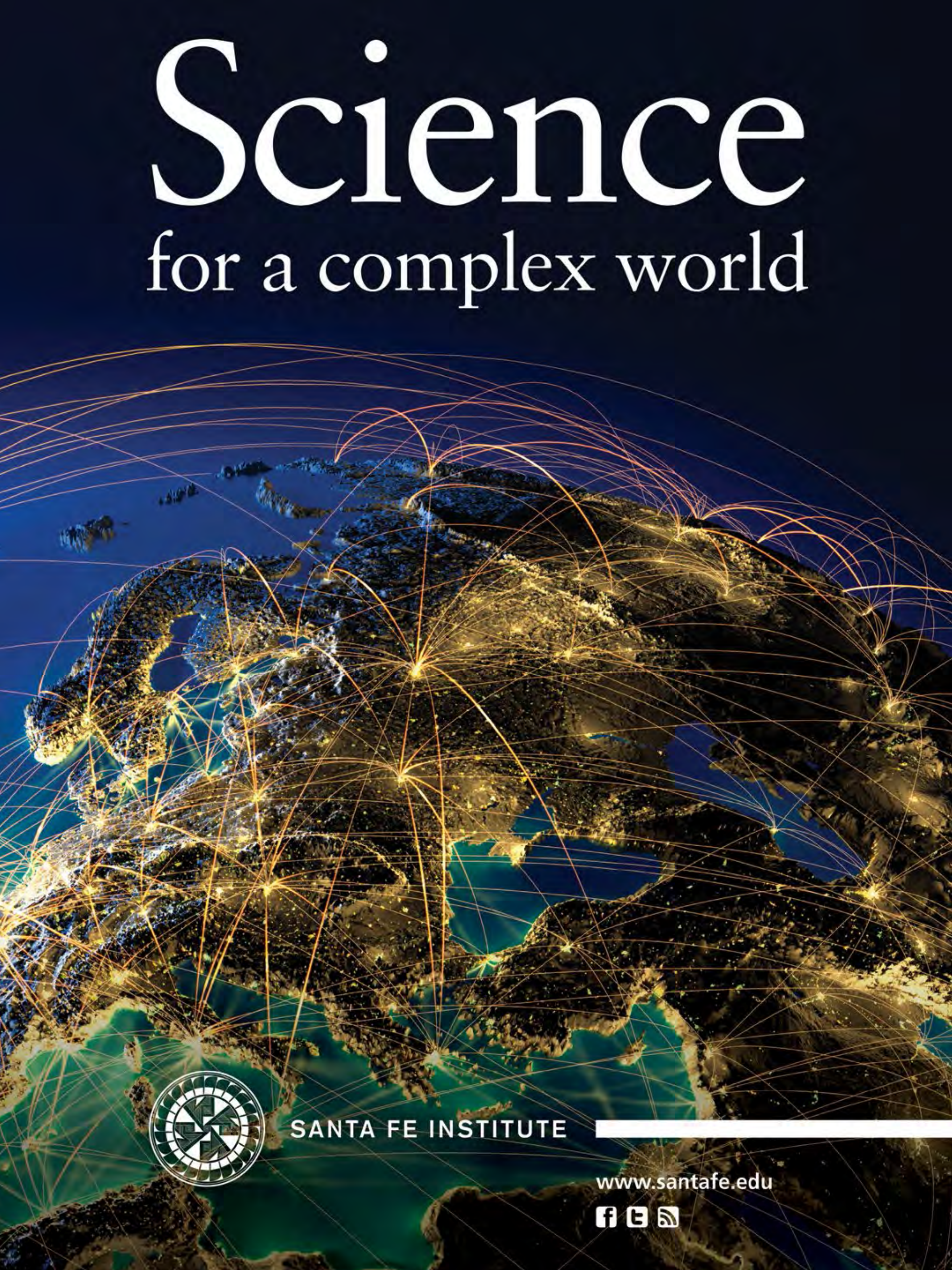
Genius

The powerful, evolving category

THEME ART Never Ever Even = Katherine Guillen + Eleanor Davis


Science
for a complex world
SANTA FE INSTITUTE
www.santafe.edu

NAUTILUS

Publisher and Editorial Director, **John Steele** *Editor in Chief,* **Michael Segal**

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Nautilus has received financial support from a John Templeton Foundation grant.

Preludes

ZOOLOGY

The Intelligent Life of the City Raccoon

Adapting to the urban jungle has made Rocky smarter

LAST WINTER TORONTO RESIDENT Simon Treadwell wheeled a garbage bin baited with a smelly mixture of wet and dry cat food, sardines, and fried chicken onto a snow-bound lot next to his property. He sprinkled the mix on and around the bin, checked his three motion-activated night vision cameras, and left.

Treadwell was testing a new lid latch in response to the city of Toronto's request to replace the green bins which residents use to discard compostable garbage. The city's raccoons had learned to fiddle with latches or overturn the bins, causing latches to pop. Even Toronto Mayor Rob Ford confessed that his family was too frightened to take out the trash. "We've devised all sorts of ways of protecting our garbage, which all fail," says Michael Pettit, who studies the history of animal behavior at York University, adding that unlike many animals, raccoons flourished rather than receded in the face of human expansion.

The urban environment may have contributed to raccoons' intelligence. In humans, the effect is well known. Psychologist Walkiria Fontes found that urban students scored better than rural students in fluid intelligence—the ability to think logically and solve problems in novel situations, independent of acquired knowledge. Harvard economist Edward Glaeser, author of *Triumph of the City* concurs. "Cities are machines for learning. They offer a maelstrom of activities," Glaeser says. "I'm sure it must be for animals as well, a range of possibilities to learn from and learn about."

York University psychologist Suzanne MacDonald videotaped rural and city raccoons toying with locked containers and compared their problem-solving skills. She found that urbanites trump their country cousins in intelligence and abilities. One persistent urban raccoon learned to open the door to her garage by standing on an overturned flowerpot and pulling and pushing on the round door handle with its five-digit paws. "Raccoons in the city are extraordinary, not only in their ability to approach things, but they have no fear, and they stick with it, they'll spend hours trying to get food out of something," MacDonald says. Treadwell seconds her. "They do go around trying systematically different things around that bin," he says. "They play until something moves and then they keep working at that."

With some luck, his invention may turn raccoons' learning skills against them. His latch system requires an opposable thumb, which raccoons don't have. After struggling to open his bins for five nights, raccoons started to lose interest. In the end, they ate the mix around the bin and left. "It looked like they learned it was a waste of time and moved on," Treadwell says. "But to draw this conclusion you'd have to do a larger test."

That test is coming next year when the city will choose the bin contract winner. Raccoons beware: At least 500,000 bins will be manufactured.

—*By Jude Isabella*

BLOGTO.COM, JUNE 2007

ILLUSTRATION BY MICHAEL BYERS

MEDICINE

Take Two Sugar Pills and Call Me in the Morning

Genetics tests can predict when placebos may be the best medicine

YOUR DOCTOR MAY SOON prescribe you sugar pills, saying they'll treat your condition as well as any drug.

According to a number of recent clinical studies, people who improve on placebos are genetically different than those who don't. What's more, these people don't even need to be deceived.

Placebos appear to work by triggering neurotransmitters, such as dopamine, that turn on the brain's reward system. And research has suggested that particular DNA variations that fine-tune this process underlie the response in conditions ranging from major depression to arthritic pain.

For example, in 2012, Ted Kaptchuk and Kathryn Hall, researchers at Beth Israel Deaconess Medical Center and Harvard Medical School in Boston, reported that versions of a gene called *COMT* could predict placebo responses in people with irritable bowel syndrome (IBS). The gene encodes an enzyme that breaks down dopamine in the brain, and people with different versions have varying levels of dopamine. Of 104 study participants, those with one particular *COMT* type responded well to a sham acupuncture treatment.

If the early studies hold up, pharmaceutical companies will likely be the first to test people for placebo-responsive genes. Many experimental drugs flunk in clinical trials because they fail to prove superior to the placebo. If a genetic test could weed out placebo responders before they enter the trial, drug companies would have a better chance of success.

In the near future, some doctors hope to put the genetic tests into practice. Once the evidence supporting them is in, Hall believes "medicine will change" for placebo responders.

Walter A. Brown, a psychiatrist at the Warren Alpert Medical School of Brown University in Rhode Island and the author of *The Placebo Effect in Clinical Practice,* agrees. "I might have a bottle of pills in my office that were green or yellow," he says, "I'd give [my patients] those and say, 'Look, these capsules don't contain any active medicine. Some people call them placebos, but a lot of people with your condition improve with this, and it may be that the fact of taking these stimulates the body's own healing processes.' "

—Elie Dolgin

Placebos could be routinely prescribed by doctors.

ILLUSTRATION BY SERGE BLOCH

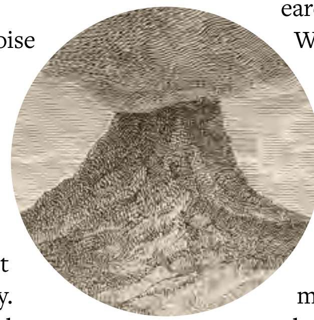
PHYSICS

The Sound So Loud That It Circled the Earth Four Times

The unimaginable violence of the Krakatoa eruption

O**N AUGUST 27, 1883,** the Earth let out a noise louder than any it has made since.

It emerged from the Indonesian island of Krakatoa and was heard 3,000 miles away on the Indian Ocean island of Rodrigues, where it sounded "like the distant roar of heavy guns." That is like being in Boston and clearly hearing a noise coming from Dublin, Ireland. It is the most distant sound that has been heard in recorded history.



What could possibly create such an earth-shatteringly loud noise? A volcano on Krakatoa had just erupted, tearing the island apart and creating a tsunami with waves over 100 feet high. The event destroyed 165 coastal villages.

The British ship Norham Castle was 40 miles from Krakatoa at the time. The ship's captain wrote in his log, "So violent are the explosions that the eardrums of over half my crew have been shattered. My last thoughts are with my dear wife. I am convinced that the Day of Judgment has come."

IN GENERAL, SOUNDS ARE CAUSED not by the end of the world but by fluctuations in air pressure. When you hum a note, you're wiggling air molecules back and forth many times per second, causing the air pressure to be low in some places and high in others. The louder the sound, the larger the fluctuations in pressure. At some point, the fluctuations are so large that the low-pressure regions hit zero pressure—a vacuum. This limit happens to be about 194 decibels for a sound in Earth's atmosphere. Any louder and the sound is no longer just passing through air, it's pushing air, creating a pressurized burst known as a shock wave.

Close to Krakatoa, the noise was well over this limit, producing a blast of high-pressure air so powerful that it ruptured the eardrums of sailors 40 miles away. Well over 3,000 miles into its journey, the pressure wave grew too quiet for humans to hear, but it continued to sweep onward. For up to five days after the explosion, weather stations in 50 cities around the globe observed a spike in barometric pressure recurring like clockwork, approximately every 34 hours. That's how long it takes sound to travel around the planet.

The atmosphere was ringing like a bell.

—Aatish Bhatia

DISCOVERY

One Question for Alan Lightman

What does epiphany in science feel like?

I**'D BEEN WORKING ON** this problem for months and began sleeping in my graduate room office, keeping cans of sardines in the drawer. Then one morning I woke up with this buzz in my head. I had a sensation familiar to me from sailing. If the wind is strong, a boat can get on top of the water and suddenly all of the water resistance vanishes and you feel like you're skimming like a stone, like this giant hand has taken hold of the mast and just yanked you forward. I took out my pages of calculation and in about five or six hours I had the answer. That was a beautiful, beautiful moment.

— Alan Lightman is a physicist, novelist, and professor of the practice of the humanities at the Massachusetts Institute of Technology.

How Jocks and Mathletes Are Alike

Success in sports can come down to how well your neurons play

BY SARAH ZHANG

ILLUSTRATIONS BY SACHIN TENG

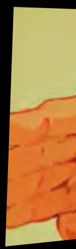
FROM BULGING BICEPS TO 7-foot wingspans, elite athletes often resemble human mutants. But it's not only their bodies that are different; their brains are just as finely tuned to the mental demands of a particular sport.

The Brain of an Iron Man

The Race Across America (RAAM) is a transcontinental race that makes the Tour de France look like a warm-up. From the moment cyclists set off on the West Coast, the race is a stageless 3,000 miles. The winner usually gets across the country in less than 10 days.

RAAM is an exercise in pushing the human body to its extreme physical and mental limits. After all, human bodies are not cars, mechanically running until they're completely empty; we receive powerful psychological signals to stop long before then. Even at our hungriest, thirstiest, and most tired, our bodies keep a last reservoir of energy that can be called upon in a dire situation. To get their best times, those cyclists have to tap into that reservoir.

The dorsolateral prefrontal cortex, a center of executive function, helps override pain and exhaustion and break into reserve stores of energy. It integrates signals from different parts of the brain (pain from sore calves versus a desire to win) and can issue the command to avoid temptation.

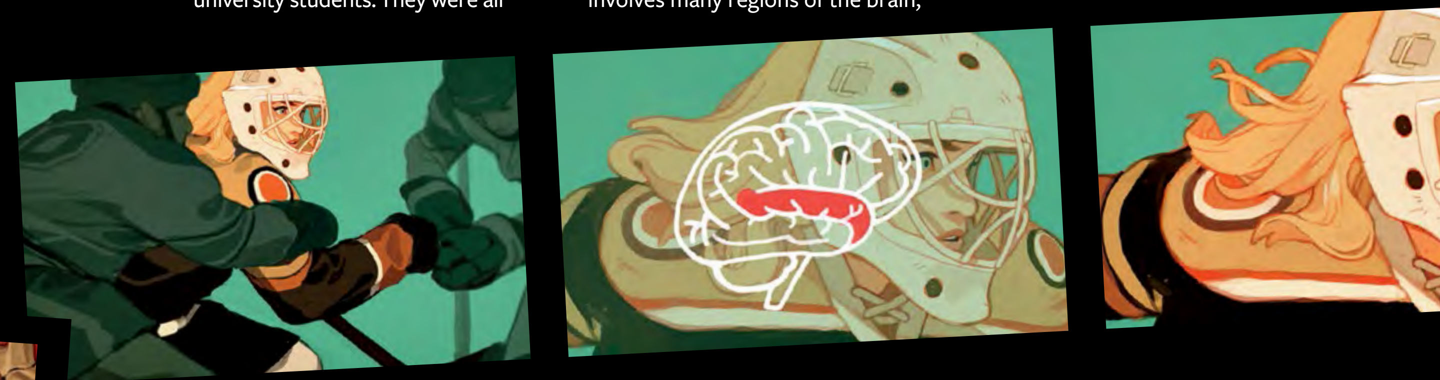


Seeing Goals in Chaos

In hockey, players zoom around as fast as 30 feet per second. Each player has to keep track of up to 11 others—plus one tiny puck flying at up to 100 miles per hour.

A 2013 study compared professional athletes, elite amateurs from the NCAA and a European Olympic training center, and non-athlete university students. They were all given a visual test called 3D-MOT, in which several spheres bounce around in 3D space; for one second, four blink red. The player then has to track these four spheres for eight more seconds. If the player succeeds, the spheres move faster, until it becomes utter chaos. The pro athletes fared the best.

Following moving targets involves many regions of the brain; one structure neuroscientists have focused on is the superior temporal sulcus, a ridge of brain tissue that that runs behind each ear, and is involved in biological-motion perception. Hockey players are known for their brawn (and brawls), but it's their brains that have to track whom to pass to and whom to bypass.



Packing a Punch Into One Inch

At the 1964 Long Beach International Karate Championships, Bruce Lee stood, right arm outstretched, legs in a fighter's stance, and barely moved as he sent an explosive punch into the chest of an unlucky volunteer, who went reeling backward.

Instead of drawing his arm back to give it more time to gather speed, his hip, shoulder, and wrist all thrust forward at once. Crucially, each joint reaches its peak acceleration at the same time.

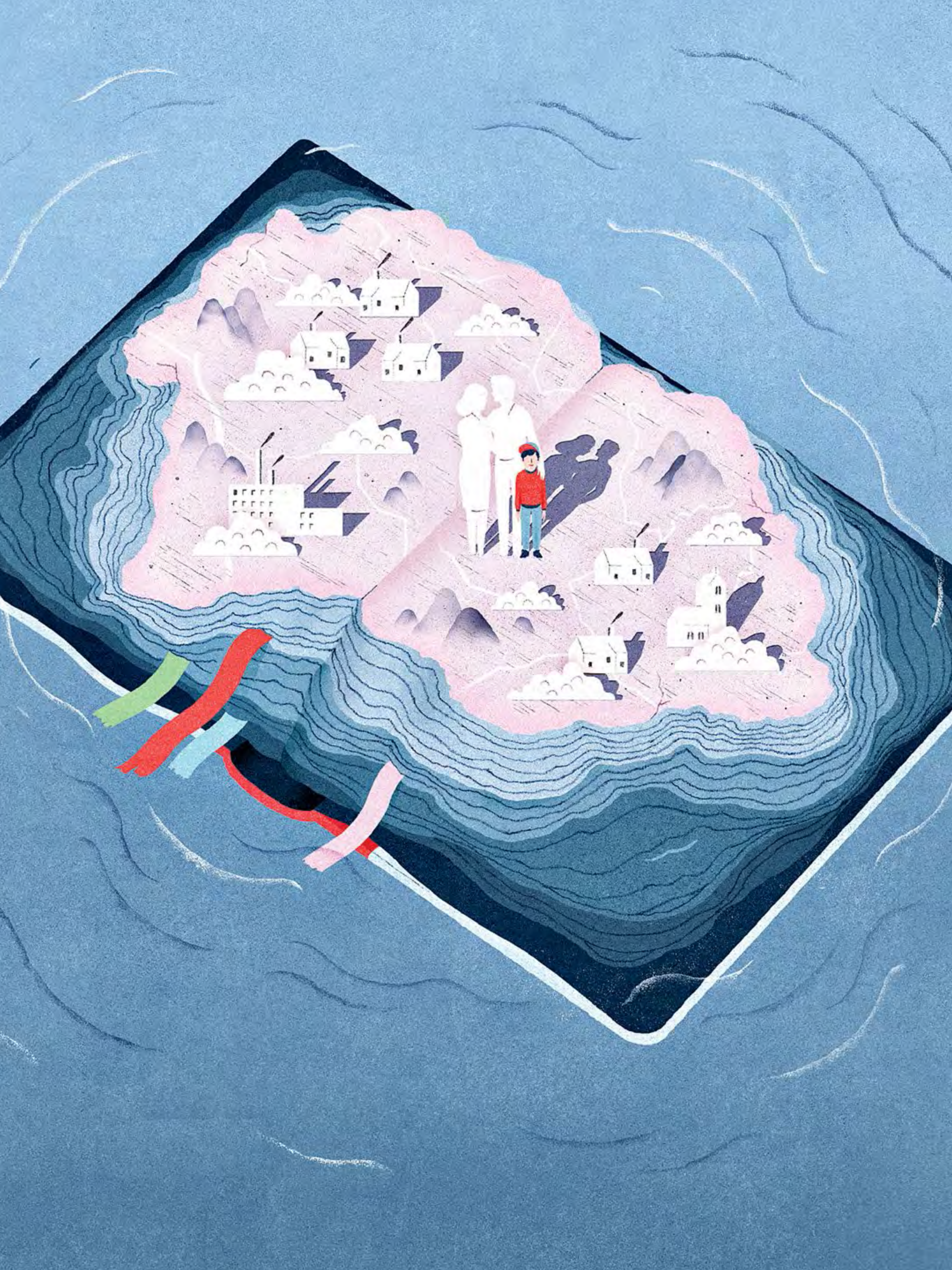
This exquisitely precise coordination goes back to the brain. A 2012 study looked at the brains of 12 black-belt karate experts, and found that they had more white matter in the superior cerebellar peduncles (SCPs), a bundle of nerves that run from the cerebellum, which is responsible for coordinating our movements.

The longer the punchers had been training and the earlier they started, the more enhanced the white matter in their SCPs.

Winning a Battle of Wills

At its core, baseball is an intense one-on-one matchup between pitcher and batter. If the batter can guess what kind of pitch is coming or its location, his chances of getting a hit go way up. The pitcher, of course, tries to make sure the batter doesn't know what to expect. In neuroscience labs, volunteers also try to outsmart each other—but the stakes are small amounts of cash rather than home runs. One study put volunteers into an MRI machine one at a time, where they had to pick a number from zero to 100 that they thought would be closest to two-thirds of the group average. Those who thought the most carefully about the strategies of their opponents showed high activity in one particular brain area involved in higher cognitive function: the medial prefrontal cortex.

This area may have a role in baseball strategy, as well. A pitcher's medial prefrontal cortex might, for example, be involved in a decision to choose a fastball or curveball.



The Rhythm of the Tide

When I heard that data from a small island community had proven humans are still evolving, I had to visit myself

BY SCOTT SOLOMON

STANDING DEEP INSIDE the archives of the Roman Catholic Church's Canadian headquarters, it suddenly struck me that this was an odd place to find evidence that people are still evolving.

That human evolution has continued into modern times was, until recently, a mostly theoretical idea debated among experts because there simply was no data. But as an evolutionary biologist, I had my own perspective. My research has mostly been on ants, which are common and diverse, making them ideal subjects for understanding evolutionary processes. In some ways ants and humans have a lot in common. Leafcutter ants create enormous underground nests that house millions of individuals, each with specialized tasks—not unlike our cities. They grow their own food in the form of a fungus that they domesticated from wild ancestors, much like human farmers. Ants even use antibiotics to treat diseases. I knew that these characteristics had not buffered them from natural selection, so why should we humans be any different?

Then in 2011, I read a study suggesting that small evolutionary changes had taken place among people living as recently as the 19th and 20th centuries.[1] I decided that I had to go see the evidence for myself, so I arranged to visit the tiny Quebec island of Ile aux Coudres in the St. Lawrence River. Here was a chance to glimpse firsthand how our very recent evolutionary past meets our present.

THE STUDY LEADER, EMMANUEL MILOT, met me in the arrival area of Montreal's Pierre-Elliott-Trudeau airport wearing a black T-shirt with a white Jesus fish emblazoned with the word "DARWIN," leaving little doubt that he was a fellow evolutionary biologist. After a short driving tour of downtown Montreal, we ducked into a microbrewery in the historical district to escape a sudden downpour that made the cobblestone streets glow yellow with light reflected from the streetlamps.

Milot told me how he had started out working as

ILLUSTRATION BY GRACIA LAM

a field research assistant surveying birds in remote parts of Quebec, before pursuing doctoral work on the wandering albatross in the Kerguelen Islands, a rugged French outpost in the southern Indian Ocean near Antarctica. The wandering albatross is an iconic species for bird enthusiasts, and Milot described his project as a sort of ornithological holy grail. He spent months at a time on French research vessels traveling to distant parts of the archipelago taking blood samples and other measurements. He once caught an albatross with a band around its leg indicating that it had been alive and breeding before Milot was even born.

Working with such a long-lived species got him thinking about issues that don't affect animals with shorter lives, like how long it takes for a young bird to reach maturity and begin to reproduce, and how the body begins to break down with old age. It wasn't long before Milot would make the connection between his birds and another long-lived species—humans.

In this he was helped by his colleague and former supervisor Francine Mayer, whom we visited the next morning. In the flower-filled garden behind her house, Mayer explained how, as a graduate student, she became interested in the demographic and genetic structure of human populations and how they change through time. In the 1960s, she was part of a research group that started to search for isolated communities where records were available on a fairly small population over multiple generations.

As an island, Ile aux Coudres was ideal. Although it is only a mile and a half from the north shore of the Saint Lawrence, dangerous currents and icy conditions during part of the year kept its inhabitants from being as closely connected to nearby villages as were other communities. What's more, another researcher, Pierre Philippe, had visited the island in 1967 and obtained permission from the community and from the local priest to transcribe parish birth, death, and marriage records for demographic research. Together with her graduate student Mireille Boisvert, Mayer worked for three years to construct a genealogy describing the marriages of 572 women and their 4,002 children, spanning from 1800 through the 1960s.

Milot joined the research team as a postdoc in 2009 and discovered a surprising trend in the birth data. Over just a few generations, the average age at which a woman became a mother dropped from 26 to 22. It seemed that those women on Ile aux Coudres who started having children at younger ages also had larger families. Intriguingly, their daughters tended to do the same.

Milot knew from his studies of birds that the timing of reproduction is a trait that often responds to natural selection. A handful of other studies on historical human populations hinted that natural selection might also affect birth timing in humans, but no definitive test had proven it.[2] To do so, he would need to show that there was a genetic basis for the decrease in age at first reproduction and that factors other than natural selection (like improving nutrition and healthcare) did not fully explain the changes. Using a mathematical model borrowed from the study of animal breeding, he was able to tease apart these factors.

The model predicted how similar any two individuals should be based on how closely related they are, taking into account their similar environment. This allowed Milot to calculate the "predicted breeding value" of age at first reproduction, which is an estimate of the extent to which the value of that trait is explained by a person's genes, and how it compares to the population average. If, for example, a particular woman had her first child at age 23, and the average age at first reproduction in the population were 25, her breeding

FROM BIRDS TO PEOPLE Evolutionary geneticist Emmanuel Milot began his career studying population genetics in birds, before turning to humans.

ALL PHOTOS COURTESY OF SCOTT SOLOMON

value would estimate how much of that two-year difference was inherited from her parents. Over eight generations, the average predicted breeding value dropped significantly, suggesting an evolutionary response.

Milot and his colleagues also found no evidence that the population's health was changing in a meaningful way over this period, by using infant and juvenile survival rates as a proxy for overall health. The team also excluded the possibility that random genetic fluctuations could account for changes in age at first reproduction by determining that the more closely related any two women were, the more likely they were to have given birth to their first child around the same age.

The best remaining explanation for the observed decrease in the age at first reproduction was evolution by natural selection. Darwin had his Galapagos finches; Milot had his Quebecois islanders.

LOW TIDE The strong tidal changes around Ile aux Coudres isolated its population from surrounding communities in the Saint Lawrence Valley before the advent of modern transportation.

THE NEXT DAY MILOT and I began our journey towards Ile aux Coudres. As we approached Quebec City, we passed the spot where the British secretly climbed a cliff and surprised the French army, beginning the 1759 battle that would end France's control of Quebec. The Quebecois were descendants of French settlers who, beginning in 1608, founded a series of settlements along the Saint Lawrence known as Nouvelle France. French immigration effectively ended following their defeat by the British, and French Canadians became isolated not only from their French ancestors but also from their neighbors, due to linguistic and religious differences.

The pattern of settlement and migration by the French Canadians was, in a way, a microcosm of the history of the human species. The first *Homo sapiens* began migrating out of northeast Africa around 50,000 years ago, establishing small populations in the Middle East. As the population grew, waves of settlers expanded west into Europe and east into Asia. Some particularly adventurous pioneers made their way across stretches of open ocean to colonize the islands of Indonesia and the South Pacific, as well as Australia, while a different wave of nomads crossed the Bering Strait and became the first people to settle the Americas.

French Canadian migration followed a similar pattern: As the population of Quebec City grew, a few pioneers would set up farms on the frontier, and their descendants would grow in numbers and then migrate to new territories, repeating the cycle. The first settlers to reach Ile aux Coudres were 30 families that arrived between 1720 and 1773. At the time, the island was at the edge of settled territory in Nouvelle France. All land on the island was divided up among the families in long, thin strips that allowed access to the sea as well as space for planting crops. The population more than doubled between 1765 and 1790, and families were forced to divide their strips of land among their children. By the beginning of the 20th century the population exceeded 1,000, reaching 1,585 inhabitants by 1950.

Women on Ile aux Coudres averaged between six and 10 surviving children. In their research article, Milot and his colleagues emphasized that the island inhabitants experienced "natural fertility," meaning that no effective forms of birth control or family planning were available. Industrialization tends to reduce both birth rates and death rates, a phenomenon known as the "demographic transition." Remarkably, as of the 1960s when Pierre Philippe assembled his dataset from church records, Ile aux Coudres had not yet gone through this transition.

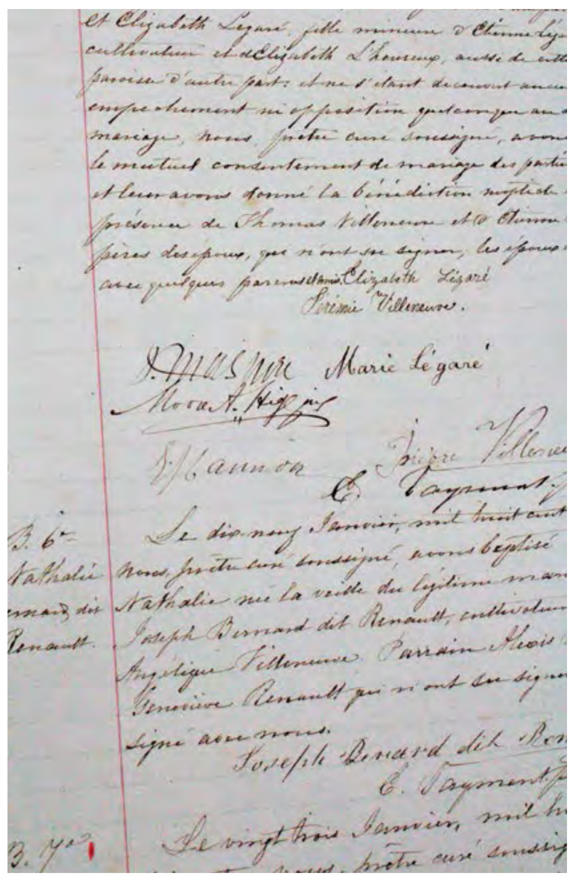
COPIES OF THE RECORDS from parishes throughout Quebec, including those from Ile aux Coudres, are kept in the archives of the Quebec Seminary. I wanted to see the raw data for myself, so Milot and I drove through the cobblestone streets of historic lower Quebec City and up a steep hill to the massive complex of five-story stone buildings that comprise the Archdiocese of Quebec, the central administrative branch of the Roman Catholic Church in Canada.

There we met Diocesan Archivist Pierre Lafontaine, a casually dressed middle-aged man who spoke quietly, apologizing for his English, which he rarely had occasion to use. Lafontaine led us into a large room with three tables forming a crescent, where he had set out several books in anticipation of our visit.

One of the oldest looking books had a faded red cover with gold text and elaborate patterns on the spine. Lafontaine explained that it contained the decrees issued by the Council of Trent in the middle of the 16th century. One decree specified that all Catholic parishes must keep detailed records of the major life events of its members. On the same table sat a scruffy-looking

Here was information that Milot and I could never hope to obtain for any other species than humans.

THE RAW DATA Detailed records of births, deaths, and marriages recorded by parish priests and kept at the Quebec Seminary.


et Elizabeth Légaré, fille mineure d'Étienne Lé
cultivateur et d'Elizabeth L'heureux, aussi de cette
paroisse d'autre part: et ne s'étant découvert aucun
empêchement ni opposition quelconque au
mariage, nous, prêtre curé soussigné, avons
le mutuel consentement de mariage des parties
et leur avons donné la bénédiction nuptiale
présence de Thomas Villeneuve et d'Étienne
pères des époux, qui n'ont su signer, les époux
avec quelques parents. Marie Elizabeth Légaré
Sévérin Villeneuve.
Marie Légaré
B. 6e Nathalie Bernard dit Renault
Le dix-neuf Janvier, mil huit cent
nous, prêtre curé soussigné, avons baptisé
Nathalie née la veille du légitime mariage
Joseph Bernard dit Renault, cultivateur
Angélique Villeneuve. Parrain Alexis
Geneviève Renault qui n'ont su signer
signé avec nous.
Joseph Bernard dit Ren
B. 7e
Le vingt-trois Janvier, mil h
nous, prêtre curé soussig

ARRIVING AT ILE AUX COUDRES Thanks to regular ferry service, Ile aux Coudres, once an isolated community, is now a popular tourist destination.

book with a hand-written label on the cover that read "De 1859 – 1866." It contained records of the baptisms, weddings, and funerals from those years—the raw data Milot and Mayer had used.

Lafontaine then led us into a long, narrow room that resembled the stacks of a modern library, containing row after row of cataloged volumes of parish records like those we had just examined. Here was information that Milot and I could never hope to obtain for any other species than humans, the sort of data that evolutionary biologists dream of. We are accustomed to conducting expeditions to remote parts of the world to collect data on wild species in their native environments. The idea that some of the best evolutionary data could come from church archives was both astonishing and exciting.

THE NEXT MORNING MILOT and I continued driving northeast along the edge of the Saint Lawrence. The drive became increasingly scenic as the river widened and highway 138 veered inland through rolling green hills. Milot pointed out a young bald eagle as it flew above the road, heading away from the river and into the forest. To our left was a ridge where he had once worked as a field research assistant, conducting surveys of birds in sections of forest that had recently burned. Following the signs toward Ile aux Coudres, the road veered to the right and then dropped abruptly toward the shore. The long, flat island could be easily seen across the narrow channel beneath us. There below us lived Milot's new research subjects.

After an hour waiting in line, we drove aboard the Joseph-Savard, one of two ferries in operation on the busy Saturday morning and named for one of the original settlers on the island. Despite the river's apparent tranquility, it was low tide, and a few rocks could be seen poking out above the surface. Swirls and ripples hinted at the strong currents that made this section of the Saint Lawrence a treacherous place to cross in smaller vessels, contributing to the historical isolation of the island's inhabitants. It was especially dangerous in winter, when much of the river was frozen, though that was difficult to imagine on a warm summer day.

Twenty minutes later, we drove off the ferry, past a sign welcoming visitors that translates as, "Ile aux Coudres, with the rhythm of the tide." The main road on the island is a two-lane affair that winds around the periphery of the island, variously perched atop a cliff with views that stretch across the Saint Lawrence to the hills of Charlevoix, or right up along the coast where the rising tide laps against a rocky beach. As we reached the southern end of the island, the road turned abruptly by a field of wildflowers that cascaded down the cliff to the shore below. We stopped at a small boulangerie where a pleasant-looking patio overlooks the river. Inside was a long line of people waiting to purchase bread and pastries, including a sweet Quebec specialty whose name, *pets de soeurs*, translates as "nun's farts."

As Milot and I entered, a smiling woman approached us and introduced herself as Noëlle-Ange Harvey, the owner of the bakery. She explained in rapid French that her family has always lived on the island, and then pointed excitedly to a nearby wall with a framed black and white photo of a small girl blowing white fluffy seeds from a dandelion. The photo, she explained, was a screenshot from the first of a series of famous documentaries by Pierre Perrault about the island—and she was the little girl. She had purchased the bakery nine years ago from the family who first opened it in 1945 but, with an eye toward history, kept the original name—Boulangerie Bouchard.

The bakery was certainly doing good business with the weekend tourists, who had become a major source of income for islanders.[3] Tourism to the region began back in the second half of the 19th century, as wealthy Americans looking to escape uncomfortable summers in the crowded cities of the northeast United States began visiting the Charlevoix region around Ile aux Coudres. This new source of income meant that islanders were no longer dependent on farming and fishing to make a living. The Pednault family planted an apple orchard on the island in 1918, and later opened a cider business that catered to tourists and would became one of Ile aux Coudres' best-known products. Hotels were built, and the old mill, which used to grind the wheat into flour for islanders, became a tourist attraction.

THE OLD MILL The mill's transformation into a tourist attraction is one sign of modernization on the island.

Tourism is just one aspect of how the island has changed. By the 1960s, when the Perrault documentaries were filmed, many of the seafaring traditions of generations past had nearly been forgotten. The first film follows the reenactment of an old island tradition in which a row of wooden poles creates a fence that traps beluga whales when the tide goes out—hunting with the rhythm of the tide.[4] Only a few of the old-timers remembered the details, but they decided to try it themselves for the sake of passing on the tradition. In the end, they captured a lone beluga and donated it to an aquarium in New York City.

Leaving the bakery, Milot and I headed south toward the village of Saint Louis at the southern end of the island. We passed a cemetery with tombstones that repeated a surprisingly short list of names—Harvey, Tremblay, Boudreault, Dufour, Pednault, Mailloux, Desgagnés—a reminder of how small this community has been. But while the entire village and its church looked much the way they did in historical photos from the early 1900s, it was clear from our brief visit that the 21st century had arrived. An old, silver-haired man sitting in a rocking chair on his front porch near the church waved to us and offered a friendly "*bonjour*" just as I imagine his grandfather would have 100 years ago, only now he did so after first removing his iPod headphones.

Modernization meant that the conclusions made by Milot, Mayer, and their colleagues about natural selection in humans could not be so easily extended to the people living here today. Medicine, technology, education, and other benefits of industrialized life mean that the age at which a woman has her first child today is affected by a great many factors, making it a less heritable trait than it used to be. Around the world, the average age at which women become mothers has been increasing in developed nations, rising in the U.S. from 21.4 in 1970 to 25 in 2006.[5]

The precise reasons for this rise have been debated, but at least one factor is education—when women spend more time in school, they delay starting a family.[6] Other factors include access to birth control and better career opportunities. It seems societal pressure is encouraging women to begin having children later in life, while natural selection favors starting young.

How will this tug of war between evolution and culture be resolved? The short answer from evolutionary biologists is that we simply do not know. The incredible control we now have over our own survival and reproduction means that the interactions between our genes and our culture is more important than ever before in our species' history.

MILOT AND I HAD to leave Ile aux Coudres the next afternoon. Before boarding the ferry, we drove back through Saint Louis, past the old stone church where Sunday mass was in progress. Just up the road, the same silver-haired man was still seated on his front porch, rocking slowly in his chair to the music from his headphones. The boulangerie was bustling with tourists, and the picnic tables overlooking the river were full. Nearby, a softball game was underway, and judging by the number of cars in the parking lot it seemed to attract a much larger crowd than the church.

Crossing the olive waters of the Saint Lawrence, Milot and I looked back at the island—different than it used to be, not as isolated, busy combining tradition and modernity in its own ways. From our perch on the ferry, navigating the once treacherous channel between the island and the mainland, what struck me most was the idea that natural selection would never stop—for people here or anywhere. Just as the tide will keep rising and falling, future generations will be born and have their own children, passing on both their genes and their culture. Our descendants will be different from us in some ways that are predictable and others that are not. After all, we are—like ants, albatrosses, and every other species on earth—a work in progress.

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SIR
ISAAC
NEWTON
QUESTIONS

The Loneliest Genius

Isaac Newton spurned social contact—but his greatest work borrowed from the ideas of others

BY LEONARD MLODINOW

DESCRIBING HIS LIFE, shortly before his death, Newton put his contributions this way: "I don't know what I may seem to the world, but, as to myself, I seem to have been only like a boy playing on the sea shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay undiscovered before me."

One thing Newton never did do, actually, was play at the seashore. In fact, though he profited greatly from occasional interaction with scientists elsewhere in Britain and on the Continent—often by mail—he never left the vicinity of the small triangle connecting his birthplace, Woolsthorpe, his university, Cambridge, and his capital city, London. Nor did he seem to "play" in any sense of the word that most of us use. Newton's life did not include many friends, or family he felt close to, or even a single lover, for, at least until his later years, getting Newton to socialize was something like convincing cats to gather for a game of Scrabble. Perhaps most telling was a remark by a distant relative, Humphrey Newton, who served as his assistant for five years: he saw Newton laugh only once—when someone asked him why anyone would want to study Euclid.

Newton had a purely disinterested passion for understanding the world, not a drive to improve it to benefit humankind. He achieved much fame in his lifetime, but had no one to share it with. He achieved intellectual triumph, but never love. He received the highest of accolades and honors, but spent much of his time in intellectual quarrel. It would be nice to be able to say that this giant of intellect was an empathetic, agreeable man, but if he had any such tendencies he did a good job suppressing them and coming off as an arrogant misanthrope. He was the kind of man who, if you said it was a gray day, would say, "no, actually the sky is blue." Even more annoying, he was the kind who could prove it. Physicist Richard Feynman voiced the feelings of many a self-absorbed scientist when he wrote a book titled, *What Do You Care What Other People Think?*

ILLUSTRATION BY RALPH STEADMAN

Newton never wrote a memoir, but if he had, he probably would have called it *I Hope I Really Pissed You Off*, or maybe, *Don't Bother Me, You Ass*.

Today we all reason like Newtonians. We speak of the force of a person's character, and the acceleration of the spread of a disease. We talk of physical and even mental inertia, and the momentum of a sports team. To think in such terms would have been unheard of before Newton; not to think in such terms is unheard of today. Even those who know nothing of Newton's laws have had their psyches steeped in his ideas. And so to study the work of Newton is to study our own roots.

NEWTON'S PENCHANT FOR SOLITUDE and his long hours of work were, at least from the point of view of his intellectual achievements, great strengths. If his retreat into the realm of the mind was a boon for science, however, it came at a great cost to the man, and seems to have been connected to the loneliness and pain of his childhood.

He had come into the world on December 25, 1642, like one of those Christmas gifts you hadn't put on your list. His father had died a few months earlier, and his mother, Hannah, must have thought that Isaac's existence would prove a short-lived inconvenience, for he was apparently premature and not expected to survive.

More than 80 years later, Newton told his niece's husband that he was so tiny at birth that he could have fit into a quart pot, and so weak he had to have a bolster around his neck to keep it on his shoulders. So dire was the little bobblehead's situation that two women who were sent for supplies a couple miles away dawdled, certain that the child would be dead before they returned. But they were wrong. The neck bolster was all the technology needed to keep the infant alive.

If Newton never saw the use of having people in his life, perhaps that was because his mother never seemed to have much use for *him*. When he was 3, she married a wealthy rector, the Reverend Barnabas Smith. More than twice Hannah's age, Smith wanted a young wife but not a young stepson.

One can't be sure what kind of family atmosphere this led to, but it's probably safe to assume there were some tensions, since, years later, in notes he wrote about his childhood, Isaac recalled "threatening my father and mother Smith to burne them and the house over them."

Isaac did not say how his parents reacted to his threat, but the record shows that he was soon banished to the care of his grandmother. Isaac and she got along better, but the bar had been set pretty low. They certainly weren't close—in all the writings and scribbles Isaac left behind there is not a single affectionate recollection of her. On the bright side, there are also no recollections of his wanting to set her on fire and burn the house down.

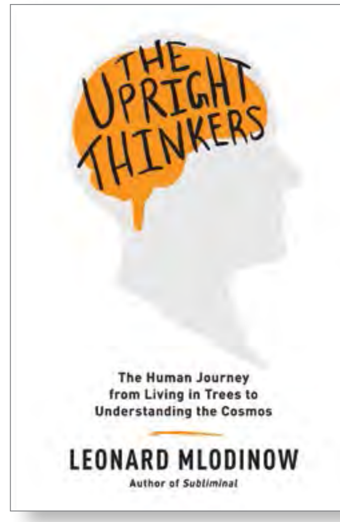
When Isaac was 10 the Reverend Smith died and he returned home briefly, joining a household that now included the three young children from his mother's second marriage. A couple of years after Smith's death, Hannah shipped him off to a Puritan school in Grantham, 8 miles from Woolsthorpe. While studying there he boarded in the home of an apothecary and chemist named William Clark, who admired and encouraged Newton's inventiveness and curiosity. Young Isaac learned to grind chemicals with a mortar and pestle; he measured the strength of storms by jumping into and against the wind, and comparing the distance of his leaps; he built a small windmill adapted to be powered by a mouse running on a treadmill, and a four-wheeled cart he would sit in and power by turning a crank. He also created a kite that carried a lit lantern on its tail, and flew it at night, frightening the neighbors.

Though he got along well with Clark, his classmates were a different story. At school, being different and clearly intellectually superior brought Newton the same reaction then as it would today—the other kids hated him. The lonely but intensely creative life he led as a boy was preparation for the creative but tortured and isolated life he would lead for most—though happily not all—of his adult life.

As Newton approached the age of 17, his mother pulled him out of school, determined that he should return home to manage the family estate. But Newton was not cut out to be a farmer, proving that you can be a genius at calculating the orbits of the planets, and a total klutz when it comes to growing alfalfa. What's more, he didn't care. As his fences fell into disrepair and his swine trespassed in cornfields, Newton built water wheels in a brook, or just read. As Richard Westfall, a Newton biographer, wrote, he rebelled against a life spent "herding sheep and shoveling dung."

Fortunately, Newton's uncle and his old schoolmaster from Grantham intervened. Recognizing Isaac's genius, they had him sent off to Trinity College in Cambridge in June, 1661. There he would be exposed to the scientific thinking of his time—only to one day rebel and overturn it. The servants celebrated his parting, not because they were happy for him, but because he had always treated them harshly. His personality was, they declared, fit for nothing but the university.

IN 1661 GALILEO'S *Discourses and Mathematical Demonstrations Relating to Two New Sciences, of Mechanics and of Motions* was just over two decades old and, like his other works, hadn't yet had much effect on the Cambridge curriculum. Which meant that in exchange for his service and his fees, Newton was treated to lessons that covered everything scholars knew about the world, as long as those scholars were Aristotle: Aristotelian cosmology, Aristotelian ethics, Aristotelian logic, Aristotelian philosophy, Aristotelian physics, Aristotelian rhetoric ... He read Aristotle in the original, he read textbooks on Aristotle, he read all the books in



the established curriculum. He finished none of them, for, like Galileo, he did not find Aristotle's arguments convincing. Still, Aristotle's writings constituted the first sophisticated approach to knowledge that Newton was exposed to, and even as he refuted them, he learned from the exercise how to approach the diverse issues of nature, and to think about them in an organized and coherent manner—and with astounding dedication. In fact, Newton, who was celibate and rarely engaged in recreational activities, worked 18 hours per day, seven days a week. It was a habit he would adhere to for many decades.

Dismissive of all the Aristotle studies that made up the Cambridge curriculum, Newton began his long journey toward a new way of thinking in 1664, when his notes indicate that he had initiated his own program of study, reading and assimilating the works of the great modern European thinkers, among them Kepler, Galileo, and René Descartes. Not a terribly distinguished student, Newton nonetheless managed to graduate in 1665, and to be awarded the title of scholar, along with four years of financial support for additional studies.

Then, in the summer of 1665, a terrible outbreak of plague afflicted Cambridge, and the school closed down, not to reopen again until spring, 1667. While the school was closed, Newton retreated to his mother's home in Woolsthorpe and continued his work in solitude. In some histories the year 1666 is called Newton's *annus mirabilis*, or miracle year. According to that lore, Newton sat at the family farm, invented calculus, figured out the laws of motion, and, after seeing a falling apple, discovered his universal law of gravitation.

True, that wouldn't have been a bad year. But it didn't happen that way. The theory of universal gravitation wasn't as simple as a single bright idea that could be had through an epiphany, it was an entire body of work that formed the basis of a whole new scientific tradition. What's more, that storybook image of Newton and the apple is destructive because it makes it seem as if physicists make progress through huge and sudden insights, like someone who's been hit on the head and can now predict the weather. In reality even for Newton progress required many hits on the head, and many years in which to process his ideas and come to a true understanding of their potential.

One reason most historians doubt the story of the miraculous epiphanies is that Newton's insights into physics during the plague period came not all at once, but over a period of three years—1664 to 1666. Moreover, there was no Newtonian revolution at the end of that period: In 1666, Newton was not yet a Newtonian. He still thought of uniform motion as arising from something internal to the moving body, and by the term "gravity," he meant some inherent property arising from the material an object is made of, rather than an external force exerted by the earth. The ideas he developed then were only a beginning, a beginning that left him baffled and floundering about many things, including force, gravity, and motion—all the basics that would eventually constitute the subject of his great work, *The Principia Mathematica*.

Bored by mathematics, and furious with the criticism of his optics, Newton had virtually cut himself off from the entire scientific community.

ON HIS RETURN TO TRINITY COLLEGE in the spring of 1667, Newton worked feverishly in two very different fields—optics and mathematics, in particular algebra. The latter paid off handsomely in that he was soon looked upon as a genius by the small community of Cambridge mathematicians. As a result, when the influential Isaac Barrow quit his prestigious post as "Lucasian professor of mathematics"—the position Stephen Hawking would hold a few centuries later—Barrow effectively arranged for Newton to take his place. The salary was magnificent by the standards of the era: Newton's university was now willing to grant him 10 times what his mother had been willing to provide—£100 per year.

Newton's efforts in optics didn't work out as well for him. While still a student he had read recent works on optics and light by Oxford scientists Robert Boyle (1627-1691), who was also a pioneer in chemistry, and Robert Hooke (1635-1703), a "crooked and pale faced" man who was a good theorist but a brilliant experimenter, as he had shown in his work as Boyle's assistant. The work of Boyle and Hooke inspired Newton, though he never admitted it. But soon he was not only calculating, he was experimenting, and he was grinding glass and making improvements to the telescope.

Newton attacked the study of light from all angles. He stuck a needle-like bodkin in his eye and pressed with it until he saw white and colored circles. Did light come from pressure? He stared at the sun for as long as he could stand it—so long it took him days to recover—and he noted that when he looked away from the sun colors were distorted. Was light real or a product of the imagination? To study color in the laboratory, Newton made a hole in the shutter of the single window in his study, and let in a sunbeam. Its white light, philosophers thought, was the purest kind, completely colorless.

Hooke had sent such light through prisms, and noted that from the prisms came colored light—transparent substances produce color, Hooke concluded.

Such observations led Newton to a theory of color and light, which he worked out between 1666 and 1670. The end result was the conclusion—it infuriated him when Hooke called it a hypothesis—that light is made up of rays of tiny "corpuscles," like atoms. We know

now that the specifics of Newton's theory are wrong. The idea of light corpuscles would be resurrected by Einstein a few hundred years later—today they are called "photons"—but Einstein's light corpuscles are quantum particles and don't obey Newton's laws.

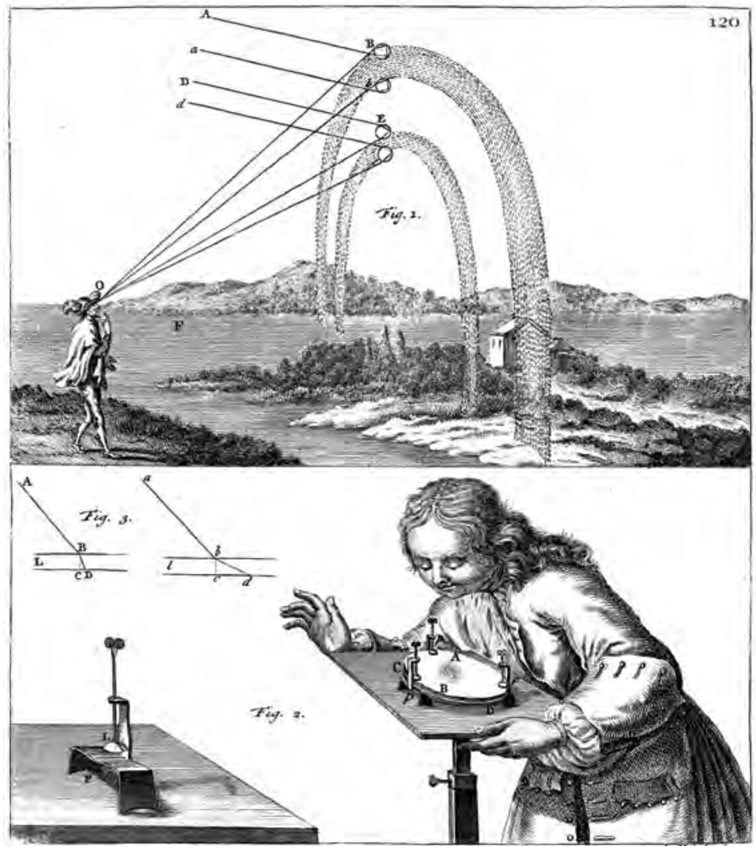
Though Newton's work on the telescope brought him fame, the idea of light corpuscles was met in Newton's day, as it would be in Einstein's, by great skepticism—even hostility in the case of Robert Hooke, whose theory had described light as consisting of waves. What's more, Hooke complained about Newton creating mere variations on the experiments Hooke had previously performed, and passing them off as his own.

Years of skipped meals and sleepless nights investigating optics had for Newton led to an intellectual battle that quickly became bitter and vicious. To make matters worse, Hooke was a brash man who shot from the hip and composed his responses to Newton in just a few hours, while Newton, meticulous and careful in all things, felt the need to put a great deal of work into his replies. In one instance, he spent months.

Personal animosity aside, here was Newton's introduction to the social side of the new scientific method—the public discussion and disputation of ideas. Newton had no taste for it. Already one who tended toward isolation, Newton withdrew.

Bored by mathematics, and furious with the criticism of his optics, by the mid 1670s Newton, in his early 30s, but with hair that was already gray and usually uncombed, had virtually cut himself off from the entire scientific community, and would remain cut off for the next decade. But there was another cause for his new, almost total isolation: Over the prior several years he had gradually turned the focus of his 100-hour work weeks to two new interests, and he wasn't anxious to discuss either of them with anyone. For good reason—those interests were decidedly outside the mainstream: the mathematical and textual analysis of the Bible, and alchemy.

Newton believed the Bible promised that the truth would be revealed to men of piety, though certain elements of it might not be apparent from a simple reading of the text. He also believed that pious men of the past, including great alchemists like the Swiss physician Paracelsus, had divined important insights, and included them in their works in a coded form to hide them from the unfaithful. After he derived his own law of gravity, he



LIGHT READING Two drawings from W.J. Gravesande's "popular" explanation of Newton's work, depicting the formation of a rainbow (top) and Newton's Rings (bottom).

even became convinced that Moses, Pythagoras, and Plato had all known it before him.

That Newton would turn his ideas into a mathematical analysis of the Bible is understandable, given his talents. His work led him to what he considered to be precise dates for the creation, Noah's ark, and other biblical events. He also calculated, and repeatedly revised, a Bible-based prediction for the end of the world. His final prediction was that the world will end sometime between 2060 and 2344.

In addition, Newton came to doubt the authenticity of a number of passages, and was convinced that a massive fraud had corrupted the legacy of the early church to support the idea of Christ as God—an idea he considered idolatrous. In short, he did not believe in the Trinity, which was ironic, given that he was a professor at Trinity College. It was also dangerous, for he would almost certainly have lost his post, and perhaps much more, had word of his views gotten out to the wrong people. But while Newton was committed to reinterpreting Christianity, he was very circumspect about allowing his work to be exposed to the public—this despite the fact that it was *this* work, his work on religion, and *not* his revolutionary work in science, that Newton regarded as his most important.

Newton's other passion in those years—alchemy—also consumed an enormous amount of time and energy, and those studies would continue for 30 years, far more time than he ever devoted to his work on physics. They consumed money as well, for Newton assembled both an alchemy laboratory and a library.

In his alchemical investigations, Newton maintained his meticulous scientific approach, conducting a myriad of careful experiments, and taking copious notes. And so the future author of the *Principia*—often called the greatest book in the history of science—also spent years scribbling notebooks full of laboratory observations such as these:

> Dissolve volatile green lion in the central salt of Venus and distill. This spirit is the green lion the blood of the green lion Venus, the Babylonian Dragon that kills everything with its poison, but conquered by being assuaged by the Doves of Diana, it is the Bond of Mercury.

Why did Newton drift so far off course? When one examines the circumstances, one factor jumps out above all others: Newton's isolation. Just as intellectual isolation led to the proliferation of bad science in the medieval Arab world, the same thing seemed to be hampering Newton, though in his case, the isolation was self-imposed, for he held his beliefs private regarding religion and alchemy, not willing to chance ridicule or even censure by opening the discussion to intellectual debate. There was not a "good Newton" and a "bad Newton," a rational and an irrational Newton, wrote Oxford philosopher W.H. Newton-Smith. Rather, Newton went astray by failing to subject his ideas to discussion and challenge "in the public forum," which is one of the most important "norms of the institution of science."

Allergic to criticism, Newton was equally hesitant to share the revolutionary work he had done on the physics of motion during the plague years. As a result, 15 years into his term as Lucasian professor those ideas remained an unpublished, unfinished work. In 1684, at the age of 41, this maniacally hardworking former prodigy had produced merely a pile of disorganized notes and essays on alchemy and religion, a study littered with unfinished mathematical treatises, and a theory of motion that was still confused and incomplete. He had performed detailed investigations in a number of fields, but arrived at no sound conclusions, leaving ideas on math and physics that were like a supersaturated solution of salt, thick with content, but not yet crystallized.

THE SEED THAT WOULD grow into the greatest advancement in science the world had ever seen sprouted after Newton met with a colleague who happened to be passing through Cambridge in the heat of late summer in 1684. In January of that fateful year, astronomer Edmund Halley—of comet fame—had sat at a meeting of the Royal Society of London, an influential learned society dedicated to science, discussing a hot issue of the day with two of his colleagues.

Decades earlier, employing planetary data of unprecedented accuracy collected by the Danish nobleman Tycho Brahe (1546-1601), Johannes Kepler had discovered three laws that seemed to describe the orbits of the planets. He declared that the planets'

At the age of 41, Newton had produced merely a pile of disorganized notes and essays on alchemy and religion, a study littered with unfinished mathematical treatises, and a theory of motion that was still confused and incomplete.

orbits were ellipses with the sun at one of the foci, and identified certain rules those orbits obey—for example, that the square of the time it takes for a planet to complete one orbit is proportional to the cube of its average distance from the sun. In a sense, his laws were beautiful and concise descriptions of how the planets move through space, but in another sense they were empty observations, ad hoc statements that provided no insight about why such orbits should be followed.

Halley and his two colleagues suspected that Kepler's laws reflected some deeper truth. In particular, they conjectured that Kepler's laws would all follow if one assumed that the sun pulled each planet toward it with a force that grew weaker in proportion to the square of the planet's distance, a mathematical form called an "inverse square law."

That a force that emanates in all directions from a distant body like the sun should diminish in proportion to the square of your distance from that body can be argued from geometry. Imagine a gigantic sphere so large that the sun appears as a mere dot at its center. All points on the surface of that sphere will be equidistant from the sun, so, in the absence of any reason to believe otherwise, one would guess that the sun's physical influence—essentially, its "force field"—should be spread equally over the sphere's surface.

Now imagine a sphere that is, say, twice as large. The laws of geometry tell us that doubling the sphere's radius yields a surface area that is four times as large, so the sun's attractive force will now be spread over four times the square footage. It would make sense, then, that at any given point on that larger sphere, the sun's attraction would be one-fourth as strong as before. That's how an inverse square law works—when you go farther out, the force decreases in proportion to the square of your distance.

Halley and his colleagues suspected that an inverse square law stood behind Kepler's laws, but could they prove it? One of them—Robert Hooke—said he could. The other, Christopher Wren, who is best known today for his work as an architect but was also a well-known astronomer, offered Hooke a prize in exchange for the proof. Hooke refused it. He was known to have a contrary personality, but the grounds he gave were suspicious: He said he would hold off revealing his proof so that others, by failing to solve the problem, might appreciate its difficulty. Perhaps Hooke really had solved the problem. Perhaps he also designed a dirigible that could fly to Venus. In any case, he never did provide the proof.

Seven months after that encounter, Halley found himself in Cambridge, and decided to look up the solitary Professor Newton. Like Hooke, Newton said he had done work that could prove Halley's conjecture. Like Hooke, he didn't come up with it. He rummaged through some papers but, not finding his proof, promised to look for it and send it to Halley later. Months passed and Halley received nothing. One can't help but

Newton's lectures seemed strangely difficult. It was later discovered why: He had simply shown up at each class session and read from his rough drafts of the *Principia*.

wonder what Halley was thinking. He asks two sophisticated grown men if they can solve a problem, and one says "I know the answer but I'm not telling!" while the other says, effectively, "the dog ate my homework." Wren held onto the reward.

Newton did find the proof he was looking for, but when he examined it again he discovered that it was in error. But Newton did not give up—he reworked his ideas, and eventually he succeeded. That November he sent Halley a treatise of nine pages showing that all three of Kepler's laws were indeed mathematical consequences of an inverse square law of attraction. He called the short tract *De Motu Corporum in Gyrum* (*On the Motion of Bodies in an Orbit*).

Halley was thrilled. He recognized Newton's treatment as revolutionary, and he wanted the Royal Society to publish it. But Newton demurred. "Now I am upon this subject," he said, "I would gladly know the bottom of it before I publish my papers."

For the next 18 months, Newton did nothing but work on expanding the treatise that would become the *Principia*. He was a physics machine. It had always been his habit, when engaged by a topic, to skip meals and even sleep. His cat, it was once said, had grown fat on the food he left sitting on his tray, and his old college roommate reported that he would often find Newton in the morning just where he had left him the night before, still working on the same problem. But this time Newton was even more extreme. He cut himself off from practically all human contact. He seldom left his room, and on the rare occasions he ventured out to the college dining hall, he'd often have just a nibble or two while still standing, and then quickly return to his quarters.

At last Newton had shut the door to his alchemical lab and shelved his theological investigations. He did continue to lecture, as was required of him, but those lectures seemed strangely obscure and impossible to follow. It was later discovered why: Newton had simply shown up at each class session and read from his rough drafts of the *Principia*.

NEWTON MIGHT NOT HAVE pushed his work on force and motion forward very much in the decades since he was voted a fellow at Trinity; but he was, in the 1680s, a far greater intellect than he had been in the plague years of the 1660s. He possessed far more mathematical maturity, and from his studies in alchemy, more scientific experience.

Ironically, one of the catalysts for Newton's breakthrough was a letter he recalled receiving five years earlier from Robert Hooke. The idea Hooke proposed was that orbital motion could be looked at as the sum of two different tendencies. Consider an object (such as a planet) that is orbiting in a circular path around some other object that is attracting it (such as the sun). Suppose the orbiting body had a tendency to continue in a straight line, that is to fly off of its curved orbit and shoot straight ahead, like a car whose driver has missed a curve in the rain. This is what mathematicians call going off in the "tangential direction."

Now suppose, also, that the body had a second tendency, an attraction toward the orbit's center. Mathematicians call motion in that direction "radial motion." A tendency toward radial motion, said Hooke, can complement a tendency toward tangential motion, so that, together, these two tendencies produce orbital motion.

It is easy to see how that idea would have resonated with Newton. Recall that, in improving on Galileo's Law of Inertia, Newton had proposed in his "Waste Book" that all bodies tend to continue moving in a straight line unless acted upon by an external cause, or force. For an orbiting body, the first tendency, to move off the orbit in a straight line, arises naturally from that law. Newton realized that if you add to that picture a force that attracts a body toward the center of the orbit, then you've also provided the cause of the radial motion that was Hooke's second necessary ingredient.

But how do you describe that mathematically, and in particular, how do you make the connection between the particular mathematical form of the inverse square law, and the particular mathematical properties of orbits that Kepler discovered?

Imagine dividing time into tiny intervals. In each interval, the orbiting object can be thought of as moving tangentially by a small amount, and, at the same time, radially by a small amount. The net of these two motions is to return it to its orbit, but a bit farther along the circle than where it had started. Repeating this many times results in a jagged circle-like orbit. However, if the time intervals are tiny enough, the path can be made as close to a circle as one might wish, and if the intervals are infinitesimal, the path, for all practical purposes, is a circle.

That is exactly the description of orbits that Newton's new mathematics—the calculus—allowed him to create. He put together a picture in which an orbiting body moves tangentially, and "falls" radially, creating a jagged path, and then he took the limiting case in which the straight line segments of the jags become vanishingly small. That effectively smooths the jagged saw-tooth path into a circle. Orbital motion, in this view, is just the motion of some body that is continually deflected from its tangential path by the action of a force pulling it toward some center. The proof was in the pudding: Employing the inverse square law to describe centripetal force in his mathematics of orbits, Newton produced Kepler's three laws, as Halley had asked.

Showing that free fall and orbital motion are both instances of the same laws of force and motion was one of Newton's greatest triumphs because it once and for all disproved Aristotle's claim that the heavens and earth form different realms. If Galileo's astronomical observations revealed that the features of other planets are much like those of the earth, Newton's work showed that the laws of nature also apply to other planets and are not unique to planet earth.

The momentous idea that gravity is universal seems to have dawned on Newton gradually, as he worked on revisions of the early drafts of *Principia*. Previously, if scientists suspected that planets exerted a force of gravity, they believed the planets' gravity affected only their moons, but not other planets, as if each planet were a distinct world unto itself with its own laws. Indeed, Newton himself had begun by investigating only whether the cause of things falling on earth might also explain the earth's pull on the moon, and not the pull of the sun on the planets. Eventually, though, he began to question the conventional thinking and wrote to an English astronomer requesting data regarding the comets of 1680 and 1684, as well as the orbital velocities of Jupiter and Saturn as they approached each other. After performing some grueling calculations on that very accurate data and comparing the results, he became convinced that the same law of gravity applies everywhere and revised the text that he published as *Principia* to reflect that.

The strengths of Newton's laws did not lie solely in their revolutionary conceptual content. With them he could also make predictions of unprecedented accuracy, and compare them to the results of experiments. For example, employing data on the distance of the moon, and the radius of the earth, and taking into account such minutiae as the distortion of the moon's orbit due to the pull of the sun, the centrifugal force due to the earth's rotation, and the deviations of the earth's shape from a perfect sphere, Newton concluded that, at the latitude of Paris, a body dropped from rest should fall 15 feet and one-eighth of an inch in the first second. This, the ever-fastidious Newton reported, matched experiments to better than 1 part in 3,000. What's more, he painstakingly repeated the experiment with different materials—gold, silver, lead, glass, sand, salt, water, wood, and wheat. Every single body, he concluded, no matter what its composition, and no matter whether on earth or in the heavens, attracts every other body, and the attraction always follows the same law.

HALLEY, PROVING HIS VALUE not just as publisher and informal editor but also as marketer, sent copies of *Principia* to all the leading philosophers and scientists of the time. The book took Britain by storm, and word of it spread quickly in coffee houses and intellectual circles all around Europe. It soon became clear that Newton had written a book destined to reshape human thought—the most influential work in the history of science. And yet one of Newton's most far-sighted observations was that the smooth pebbles and pretty shells of truth he had discovered were the beginning and not the end of our quest to understand the laws of nature, that despite the successes of his theory, a "great ocean of truth" was yet to be discovered—an ocean we would not begin to understand for another 200 years.

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“THE BIG BANG IS HARD SCIENCE. IT IS ALSO A CREATION STORY.”
ILLUSTRATION BY **JOOHEE YOON**

16

ARISTOTLE FILLED THE VOID with an invisible ether, Torricelli killed it, and Higgs has gone some way to bringing it back. The will to nothingness is the path away from meaning for Nietzsche, but the path toward meaning for the Buddhist. Some formalist approaches to mathematics define zero as a foundational symbol, while Gödel used zero to undermine formalism itself.

Our relationship with nothing is complex, contradictory, and essential. It is that shape in the corner of our vision, defining the boundaries of things but never quite in focus. What then, is it? Is it simply a construct of the human imagination, a symbol under a line in our ledgers, or is it as real as the worlds it surrounds?

Welcome to "Nothingness."

—MS

"If time, as Einstein said, is but a stubbornly persistent illusion, then we can dispense at once, not just with causality issuing from natural laws, but also with the question of where those laws came from. They didn't come from anywhere, because nothing evolves."

AMANDA GEFTER
"The Bridge From Nowhere" p. 70

Nothingness

PEERING INTO THE VOID

This Is Your Brain on Silence

Contrary to popular belief, peace and quiet is all about the noise in your head

BY DANIEL A. GROSS

ONE ICY NIGHT IN March 2010, 100 marketing experts piled into the Sea Horse Restaurant in Helsinki, with the modest goal of making a remote and medium-sized country a world-famous tourist destination. The problem was that Finland was known as a rather quiet country, and since 2008, the Country Brand Delegation had been looking for a national brand that would make some noise.

Over drinks at the Sea Horse, the experts puzzled over the various strengths of their nation. Here was a country with exceptional teachers, an abundance of wild berries and mushrooms, and a vibrant cultural capital the size of Nashville, Tennessee. These things fell a bit short of a compelling national identity. Someone jokingly suggested that nudity could be named a national theme—it would emphasize the honesty of Finns. Someone else, less jokingly, proposed that perhaps quiet wasn't such a bad thing. That got them thinking.

A few months later, the delegation issued a slick "Country Brand Report." It highlighted a host of marketable themes, including Finland's renowned educational system and school of functional design. One key theme was brand new: silence. As the report explained, modern society often seems intolerably loud and busy. "Silence is a resource," it said. It could be marketed just like clean water or wild mushrooms. "In the future, people will be prepared to pay for the experience of silence."

People already do. In a loud world, silence sells. Noise-canceling headphones retail for hundreds of dollars; the cost of some weeklong silent meditation courses can run into the thousands. Finland saw that it was possible to quite literally make something out of nothing.

In 2011, the Finnish Tourist Board released a series of photographs of lone figures in the wilderness, with the caption "Silence, Please." An international "country branding" consultant, Simon Anholt, proposed the

ILLUSTRATION BY LEONARD PENG

playful tagline "No talking, but action." And a Finnish watch company, Rönkkö, launched its own new slogan: "Handmade in Finnish silence."

"We decided, instead of saying that it's really empty and really quiet and nobody is talking about anything here, let's embrace it and make it a good thing," explains Eva Kiviranta, who manages social media for VisitFinland.com.

Silence is a peculiar starting point for a marketing campaign. After all, you can't weigh, record, or export it. You can't eat it, collect it, or give it away. The Finland campaign raises the question of just what the tangible effects of silence really are. Science has begun to pipe up on the subject. In recent years researchers have highlighted the peculiar power of silence to calm our bodies, turn up the volume on our inner thoughts, and attune our connection to the world. Their findings begin where we might expect: with noise.

The word "noise" comes from a Latin root meaning either queasiness or pain. According to the historian Hillel Schwartz, there's even a Mesopotamian legend in which the gods grow so angry at the clamor of earthly humans that they go on a killing spree. (City-dwellers with loud neighbors may empathize, though hopefully not too closely.)

Dislike of noise has produced some of history's most eager advocates of silence, as Schwartz explains in his book *Making Noise: From Babel to the Big Bang and Beyond*. In 1859, the British nurse and social reformer Florence Nightingale wrote, "Unnecessary noise is the most cruel absence of care that can be inflicted on sick or well." Every careless clatter or banal bit of banter, Nightingale argued, can be a source of alarm, distress, and loss of sleep for recovering patients. She even quoted a lecture that identified "sudden noises" as a cause of death among sick children.

Surprisingly, recent research supports some of Nightingale's zealous claims. In the mid 20th century, epidemiologists discovered correlations between high blood pressure and chronic noise sources like highways and airports. Later research seemed to link noise to increased rates of sleep loss, heart disease, and tinnitus. (It's this line of research that hatched the 1960s-era notion of "noise pollution," a name that implicitly refashions transitory noises as toxic and long-lasting.)

Studies of human physiology help explain how an invisible phenomenon can have such a pronounced physical effect. Sound waves vibrate the bones of the ear, which transmit movement to the snail-shaped cochlea. The cochlea converts physical vibrations into electrical signals that the brain receives. The body reacts immediately and powerfully to these signals, even in the middle of deep sleep. Neurophysiological research suggests that noises first activate the amygdalae, clusters of neurons located in the temporal lobes of the brain that are associated with memory formation and emotion. The activation prompts an immediate release of stress hormones like cortisol. People who live in consistently loud environments often experience chronically elevated levels of stress hormones.

Just as the whooshing of a hundred individual cars accumulates into an irritating wall of background noise, the physical effects of noise add up. In 2011, the World Health Organization tried to quantify its health burden in Europe. It concluded that the 340 million residents of western Europe—roughly the same population as that of the United States—annually lost a million years of healthy life because of noise. It even argued that 3,000 heart disease deaths were, at their root, the result of excessive noise.

So we like silence for what it doesn't do—it doesn't wake, annoy, or kill us—but what does it do? When Florence Nightingale attacked noise as a "cruel absence of care," she also insisted on the converse: Quiet is a part of care, as essential for patients as medication or sanitation. It's a strange notion, but one that researchers have begun to bear out as true.

Silence first began to appear in scientific research as

Two-minute silent pauses proved far more relaxing than either "relaxing" music or a longer silence played before the experiment started.

THE QUIET SELL A colorful sunset on the seashore in Finland, where marketers have rebranded the Nordic country with the slogan, "Silence, Please."

PETES PHOTOS, GETTY

a control or baseline against which scientists compare the effects of noise or music. Researchers have mainly studied it by accident, as physician Luciano Bernardi did in a 2006 study of the physiological effects of music. "We didn't think about the effect of silence," he says. "That was not meant to be studied specifically."

He was in for a quiet surprise. Bernardi observed physiological metrics for two dozen test subjects while they listened to six musical tracks. He found that the impacts of music could be read directly in the bloodstream, via changes in blood pressure, carbon dioxide, and circulation in the brain. (Bernardi and his son are both amateur musicians, and they wanted to explore a shared interest.) "During almost all sorts of music, there was a physiological change compatible with a condition of arousal," he explains.

This effect made sense, given that active listening requires alertness and attention. But the more striking finding appeared between musical tracks. Bernardi and his colleagues discovered that randomly inserted stretches of silence also had a drastic effect, but in the opposite direction. In fact, two-minute silent pauses proved far more relaxing than either "relaxing" music or a longer silence played before the experiment started.

The blank pauses that Bernardi considered irrelevant, in other words, became the most interesting object of study. Silence seemed to be heightened by contrasts, maybe because it gave test subjects a release from careful attention. "Perhaps the arousal is something that concentrates the mind in one direction, so that when there is nothing more arousing, then you have deeper relaxation," he says.

In 2006, Bernardi's paper on the physiological effects of silence was the most-downloaded research in the journal *Heart*. One of his key findings—that silence is heightened by contrasts—is reinforced by neurological research. In 2010, Michael Wehr, who studies sensory processing in the brain at the University of Oregon, observed the brains of mice during short bursts of sound. The onset of a sound prompts a specialized network of neurons in the auditory cortex to light up. But when sounds continue in a relatively constant manner, the neurons largely stop reacting. "What the neurons really do is signal whenever there's a change," Wehr says.

The sudden onset of silence is a type of change too, and this fact led Wehr to a surprise. Before his 2010 study, scientists knew that the brain reacts to the start of silences. (This ability helps us react to dangers, for example, or distinguish words in a sentence.) But Wehr's research extended those findings by showing that, remarkably, the auditory cortex has a separate network of neurons that fire when silence begins. "When a sound suddenly stops, that's an event just as surely as when a sound starts."

Even though we usually think of silences as a lack of input, our brains are structured to recognize them, whenever they represent a sharp break from sounds. So the question is what happens after that moment—when silence continues, and the auditory cortex settles into a state of relative inactivity.

There seemed to be brain activity that was most visible when the subject was in a quiet room, doing nothing.

One of the researchers who's examined this question is a Duke University regenerative biologist, Imke Kirste. Like Bernardi, Kirste wasn't trying to study silence at all. In 2013, she was examining the effects of sounds in the brains of adult mice. Her experiment exposed four groups of mice to various auditory stimuli: music, baby mouse calls, white noise, and silence. She expected that baby mouse calls, as a form of communication, might prompt the development of new brain cells. Like Bernardi, she thought of silence as a control that wouldn't produce an effect.

As it turned out, even though all the sounds had short-term neurological effects, not one of them had a lasting impact. Yet to her great surprise, Kirste found that two hours of silence per day prompted cell development in the hippocampus, the brain region related to the formation of memory, involving the senses. This was deeply puzzling: The total absence of input was having a more pronounced effect than any sort of input tested.

Here's how Kirste made sense of the results. She knew that "environmental enrichment," like the introduction of toys or fellow mice, encouraged the development of neurons because they challenged the brains of mice. Perhaps the total absence of sound may have been so artificial, she reasoned—so alarming, even—that it prompted a higher level of sensitivity or alertness in the mice. Neurogenesis could be an adaptive response to uncanny quiet.

The growth of new cells in the brain doesn't always have health benefits. But in this case, Kirste says that the cells seemed to become functioning neurons. "We saw that silence is really helping the new generated cells to differentiate into neurons, and integrate into the system."

While Kirste emphasizes that her findings are preliminary, she wonders if this effect could have unexpected applications. Conditions like dementia and depression have been associated with decreasing rates of neurogenesis in the hippocampus. If a link between silence and neurogenesis could be established in humans, she says, perhaps neurologists could find a therapeutic use for silence.

While it's clear that external silence can have tangible benefits, scientists are discovering that under the hoods of our skulls "there isn't really such a thing as silence," says Robert Zatorre, an expert on the neurology of sound. "In the absence of sound, the brain often tends to produce internal representations of sound."

Imagine, for example, you're listening to Simon and Garfunkel's "The Sound of Silence," when the radio abruptly cuts out. Neurologists have found that if you know the song well, your brain's auditory cortex remains active, as if the music is still playing. "What you're 'hearing' is not being generated by the outside world," says David Kraemer, who's conducted these types of experiments in his Dartmouth College laboratory. "You're retrieving a memory." Sounds aren't always responsible for sensations—sometimes our subjective sensations are responsible for the illusion of sound.

This is a reminder of the brain's imaginative power: On the blank sensory slate of silence, the mind can conduct its own symphonies. But it's also a reminder that even in the absence of a sensory input like sound, the brain remains active and dynamic.

In 1997, a team of neuroscientists at Washington University was collecting brain scan data from test subjects during various mental tasks, like arithmetic and word games. One of the scientists, Gordon Shulman, noticed that although intense cognition caused spikes in some parts of the brain, as you'd expect, it was also causing declines in the activity of other parts of the brain. There seemed to be a type of background brain activity that was most visible, paradoxically, when the test subject was in a quiet room, doing absolutely nothing.

The team's lead scientist was Marcus Raichle, and he knew there were good reasons to look closer at the data. For decades, scientists had known that the brain's "background" activity consumed the lion's share of its energy. Difficult tasks like pattern recognition or arithmetic, in fact, only increased the brain's energy consumption by a few percent. This suggested that by ignoring the background activity, neurologists might be overlooking something crucial. "When you do that," Raichle explains, "most of the brain's activities end up on the cutting room floor."

In 2001, Raichle and his colleagues published a seminal paper that defined a "default mode" of brain function—situated in the prefrontal cortex, active in cognitive actions—implying a "resting" brain is perpetually active, gathering and evaluating information. Focused attention, in fact, curtails this scanning activity. The default mode, Raichle and company argued, has "rather obvious evolutionary significance." Detecting predators, for example, should happen automatically and not require additional intention and energy.

Follow-up research has shown the default mode is also enlisted in self-reflection. In 2013, in *Frontiers in Human Neuroscience*, Joseph Moran and colleagues wrote the brain's default mode network "is observed most closely during the psychological task of reflecting on one's personalities and characteristics (self-reflection), rather than during self-recognition, thinking of the self-concept, or thinking about self-esteem, for example." During this time when the brain rests quietly, wrote Moran and colleagues, our brains integrate external and internal information into "a conscious workspace."

Freedom from noise and goal-directed tasks, it appears, unites the quiet without and within, allowing our conscious workspace to do its thing, to weave ourselves into the world, to discover where we fit in. That's the power of silence.

Noora Vikman, an ethnomusicologist, and a consultant on silence for Finland's marketers, knows that power well. She lives in the eastern part of Finland, an area blanketed with quiet lakes and forests. In a remote and quiet place, Vikman says, she discovers thoughts and feelings that aren't audible in her busy daily life. "If you want to know yourself you have to be with yourself, and discuss with yourself, be able to talk with yourself."

"Silence, Please" has proven to be the most popular theme in Finland's rebranding, and one of the most popular pages on VisitFinland.com. Maybe silence sells because, so often, we treat it as a tangible thing—something easily broken, like porcelain or crystal, and something delicate and valuable. Vikman remembers a time when she experienced the rarity of nearly complete silence. Standing in the Finnish wilderness, she strained her ears to pick out the faintest sounds of animals or wind. "It's strange," she says, "the way you change. You have all the power—you can break the silence with even with the smallest sounds. And then you don't want to do it. You try to be as quiet as you can be."

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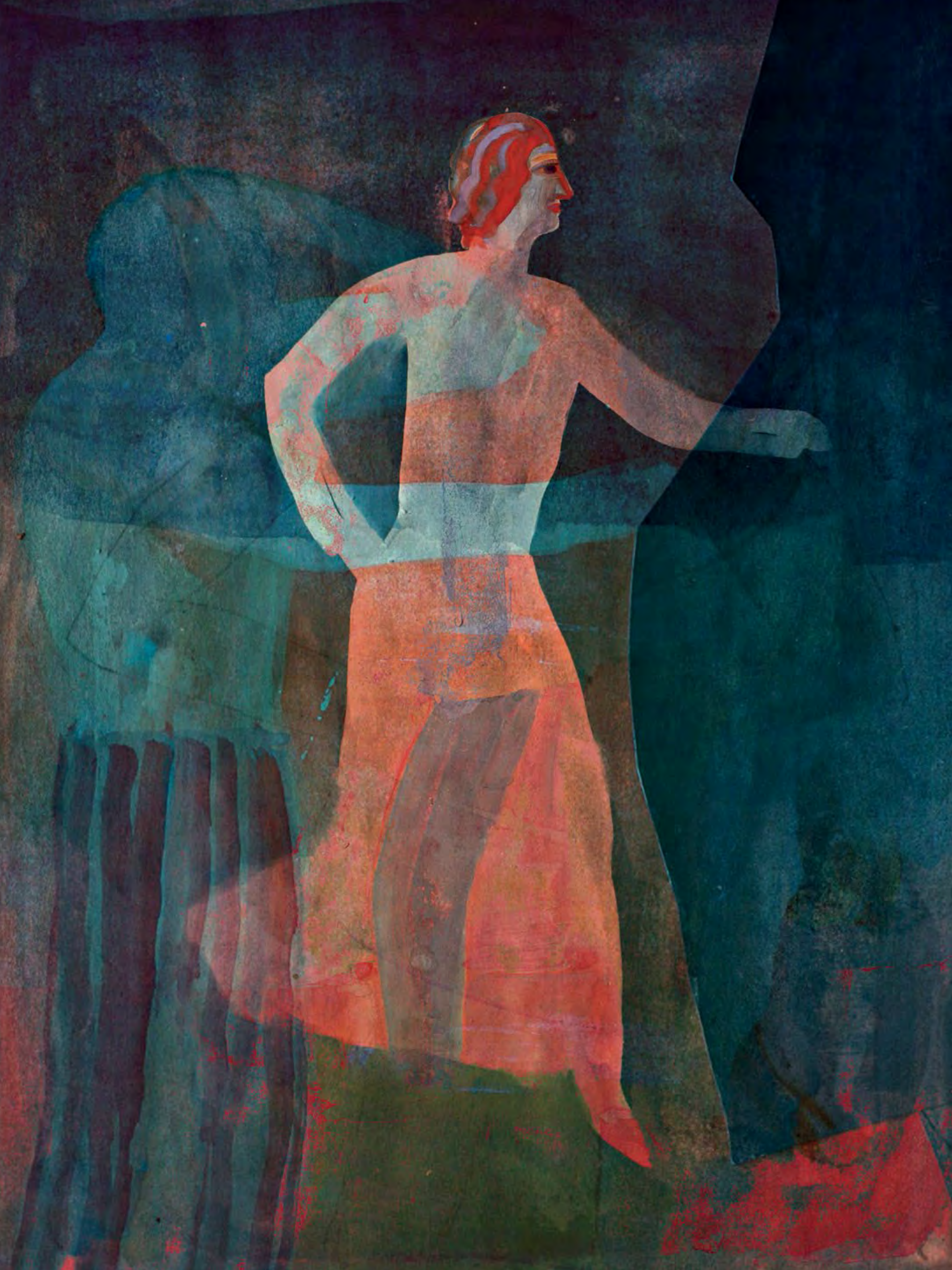


Postcards From the Edge of Consciousness

Sensory deprivation goes from CIA torture manuals to a yoga studio near you

BY MEEHAN CRIST

I AM FRESH FROM THE SHOWER, wrapped in just a towel and smelling of mild herbal soaps (both shower and soaps are required), standing at the door to the tank. It resembles a shower door—knee-high, sliding—and opens to reveal a tub bigger than a bathtub but smaller than a hot tub, with a bulge in the middle. The tub is molded from a pale blue material that reminds me of above-ground Jacuzzis from the '70s. The walls are padded with soundproof material. Overhead, the ceiling looks low enough to touch. There are no windows. Sam Zeiger had this tank built into his Chelsea apartment nearly 30 years ago and he is currently down the hall, in the living room, which has been modestly closed off from this half of the apartment by a folding screen. I am not uncomfortable, though I am, perhaps, in a state of nervous anticipation. This is my first float.

Leaving my towel outside, I step in and slide the door shut behind me. The air is humid and close. The smell reminds me of the inside of an old sailboat—salt and weathered fiberglass. The water is loaded with more salt than the Dead Sea, and both air and water are kept at skin temperature, so that as you float it is hard to say where body ends and environment begins. Once the lights are off, the darkness is total. The tank offers a reduced sensory experience as close to nothingness as you can get.

Slowly, so as not to disturb the water into motion, I lower myself down. The water feels thick. Slippery with salt. I lie back and feel for the big round button I've been told will be on my left. When I press it the lights go dark, and I begin floating.

"YOU'LL HEAR THINGS that you don't normally hear," Zeiger had said as he prepped me in his living room. "Your heart beat, your blood flow. A lot of people report hearing a quiet, high-pitched whine, which is your nervous system." The proprietor of Blue Light Floatation,

ILLUSTRATION BY VIVIENNE FLESHER

Zeiger is neither scientist nor clinician, but for the past 29 years, he has hosted a steady stream of floaters and attained something like cult status. The flotation community leans a bit New Age, and Zeiger's living room, which smells pleasantly herbal, features floor-to-ceiling bookshelves lined with titles such as *Indestructible Truth*, *You Are the Eyes of the World*, and *The Attention Revolution*. Tibetan prayer flags are draped over a lamp at one end of the brown leather couch. I have come because flotation has seen a popular resurgence in recent years, with commercial tank operators popping up across the country, and I've heard stories both fantastic and mundane about the reduced stimulus experience. It can cure terrible, lifelong phobias. It helps with chronic pain. It is a portal to other dimensions. It is relaxing.

Research suggests that something rather remarkable happens when sensory stimuli from the external world are reduced to nearly nothing. REST, or Restricted Environmental Stimulation Therapy, as floating and the related dry-chamber methods are known to researchers, has been shown to slow the heartbeat, reduce blood pressure, and release muscle tension. It increases levels of endorphins and lowers levels of adrenaline, as well as stress hormones such as cortisol. Some of these effects can be measured across sessions. Cortisol levels, for example, tend to go down after the first session, then go down further and stay down after repeated sessions. Clinically, REST has been shown to help with tension headaches, hypertension, and chronic pain, as well as performance enhancement. Basketball players, tennis players, dart players, skiers, and pilots all perform better after REST. Scores on memory and cognition tests improve. Some subjects report powerful emotional experiences, as in a particularly intense session of psychotherapy, and nearly all subjects report greater relaxation and an elevated mood after floating.

But why? *Sensory Deprivation: Fifteen Years of Research*, published in 1969 and edited by John P. Zubek, was the first authoritative overview of what was then called the "sensory deprivation" literature. The book catalogues an array of promising findings, but as REST researcher and pioneer Peter Suedfeld noted in a 1994 issue of the *Journal of Environmental Psychology*, "researchers had generated many facts, but had failed to propose and test a theory that would explain the wide-ranging and impressive changes in functioning that were evidenced during or after REST." Nearly a decade later, we have more facts and a growing store of anecdotal evidence, but a scientific explanation is far from complete. Beyond the tantalizing promise of clinical applications, a better understanding of how flotation affects the mind and body may offer insight into a common but poorly-understood twilight phase of consciousness that occurs between waking and sleeping, when the lines between conscious and unconscious begin to blur and the mind begins to unwind.

AT FIRST I CLING to the tank, fingers splayed and pressing up against the sides. Then I let go. My mind offers this: *unmoored*. The saltwater makes me so buoyant that I float without any effort at all. The darkness behind my eyelids is indistinguishable from the darkness of the tank. But I am naggingly aware of a line along my skin where water meets air. I think about this line, and whether I should be thinking about it. Some say that the experience of flotation is similar to meditation, and this is certainly reminiscent of meditation—the mind twitching and fretting like a puppy tied to a lamppost.

But the sensory experience of floating is like nothing else. The only sounds come from inside the body: the whooshing rush of each breath filling then escaping the lungs, the echoing thump of the heart in the chest. At some point (has it been five minutes? 10 minutes?), I realize I can't tell if my eyes are open or closed. When I twitch my eyelids to check, the sound of the ensuing blink is a resonant boom. A rumbling begins somewhere behind my right ear, as if a truck is coming around the curve of my head, and as it thunders past, I realize an air bubble has been loosed from my hair. There are subtler noises as well, a regular swish like the hem of a woman's dress brushing a marble floor—my blood circulating.

Suddenly, my left foot touches the side of the tank and my whole body tenses. I use my toes to push off, followed quickly by my right foot bumping up against the other side. I have pushed too hard. Though I can't see anything, I am acutely aware of the boundary the tub inscribes around me. After a few more bumps and gentle pushes, my body and the water make peace, and I stop fixating on the tank. Then I discover I can't think about the tank. I can't mentally place where the sides might be or where my body might be in relation to anything else. My brain keeps asking my body, *where am I?* And my body keeps saying, *um, I don't know...*

This is when I begin to get dizzy. I swear my body is spinning clockwise on the surface of the water, so I prepare to bump the left side of the tank, but I don't. This is wildly disorienting. It's as if the tank has disappeared and I'm spinning in endless space.

BECAUSE FLOTATION SIMULATES the weightless conditions of space, NASA has used flotation tanks to train its astronauts. (See Von Braun Takes A Dip.)

BUT BEFORE ASTRONAUTS and the New-Age embrace, there were Cold War fears about brainwashing. The reduced sensory environment of REST grew out of experiments secretly funded by the CIA in the 1950s and '60s, on what was then termed "sensory deprivation." In the early 1950s, remarkable video footage surfaced which showed American GIs taken captive in Korea denouncing capitalism and imperialism, prompting the CIA to ask: How could these extraordinary confessions have been extracted? The intelligence community suspected a powerful new mind-control technique. In a sensational and hugely popular book published in 1951, *Brain-Washing in Red China*, the journalist and secret CIA propagandist Edward Hunter proposed the term "brain-wash," a literal translation of the Chinese *his nao*, to "wash brain." If Communist powers had figured out powerful new mind-control techniques, then Western powers needed to catch up. It was a psychological arms race that could only be run by scientists studying the human mind.

The CIA's interest in sensory deprivation as a potential mechanism of brainwashing was sparked by the illustrious psychologist Donald Hebb of McGill University. Hebb is best known for the famous dictum "cells that fire together wire together," referring to a theory about neural mechanisms now foundational to modern neuroscience. Less well known is the fact that he attended a secret meeting at the Montreal

IN THE ZONE Flotation tanks minimize sensory inputs by using skin-temperature, buoyant, salted water inside a sound-proofed and darkened environment.

GETTY IMAGES

VON BRAUN TAKES A DIP Nazi rocket scientist turned American space hero Wernher von Braun emerges from the Neutral Buoyancy Simulator at Marshall Space Flight Center in 1967. The simulator recreated the experience of being in space.

Ritz-Carlton on June 1, 1951, along with high-ranking representatives from the defense departments of three countries—Britain, the United States, and Canada. At this meeting, the question of brainwashing was raised. Hebb, then chair of the Human Relations and Research Committee of the Canadian Defense Research Board, speculated that prisoners might be more malleable if placed into isolation with limited sensory input. The others were impressed. Three months later, he began research funded by Canada's Department of National Defense (and carefully monitored by the CIA) into the effects of sensory deprivation. As Alfred McCoy reports in *A Question of Torture: CIA Interrogation, From the Cold War to the War on Terror*, one stated goal of the research within the intelligence community was to prepare soldiers for being taken hostage and subjected to mind-control techniques. Hebb published the results in a 1954 issue of the *Canadian Journal of Psychology* under the guise of a study on monotonous environments such as those experienced by long-distance truck drivers.

The experimental setup Hebb designed looks very little like today's flotation tanks. Twenty-two male student volunteers were paid $20 a day, twice the average daily wage at the time, to lay on a bed in a chamber designed to induce "perceptual isolation." The students wore a translucent plastic visor that emitted diffuse light to prevent "pattern vision," as well as cotton gloves and cardboard cuffs that went from elbow to fingertips to reduce tactile stimulation. A U-shaped foam rubber pillow helped dampen auditory stimuli, but an air conditioner in the ceiling remained on 24 hours a day, emitting a steady hum of white noise. The students were allowed breaks to use the bathroom and eat meals, which many ate sitting at the foot of the bed. They were invited to stay as long as they liked, but most could not make it past two or three days.

It can cure terrible, lifelong phobias. It helps with chronic pain. It is a portal to other dimensions. It is relaxing.

The results were startling. Subjects' cognitive skills deteriorated rapidly and most experienced powerful hallucinations. As one of Hebb's graduate students, Woodburn Heron, wrote in a 1956 issue of *Scientific American*, "Our subjects' hallucinations usually began with simple forms … Then the visions became more complex, with abstract patterns repeated like a design on wallpaper, or recognizable figures, such as rows of little yellow men with black caps on and their mouths open. Finally, there were integrated scenes: e.g. a procession of squirrels with sacks over their shoulders marching "purposefully" across the visual field, prehistoric animals walking about in a jungle, processions of eyeglasses marching down a street." Some subjects experienced auditory or tactile hallucinations, as well—"one had a feeling of being hit in the arm by pellets fired from a miniature rocket ship he saw." Many participants refused to finish the experiment.

The CIA, however, was most interested in the students' receptivity to beliefs that had previously been rejected. Before going into the chamber, participants were given various tests and questionnaires, including one gauging belief in paranormal phenomena. While the participants were in the chamber, Hebb's team played "a recording of a talk arguing for the reality of ghosts, poltergeists, and other supernatural phenomena." Apparently, even those who had reported not believing in such phenomena found this talk quite convincing. "Some of them reported that for several days after the experiment they were afraid they were going to see ghosts."

Realizing the implications of his work, Hebb soon abandoned the study of sensory deprivation, but flame had been put to fire. Seven years after the McGill study was published, 230 articles on the subject had appeared in scientific journals, and behind closed doors controlling sensory environments had emerged as a way to soften prisoners before interrogation. In a confidential report to the Canadian Defense Research Board, Hebb noted that four of the students in his study "remarked spontaneously that being in the apparatus was a form of torture." In the last interview he gave before his death, he said, "It was clear when we gave our report to the Defense Board that we were describing formidable interrogation techniques."

This formidable potential was not lost on the CIA. During the 1950s and '60s, multiple CIA projects funded scientific research on psychological torture and interrogation techniques, including sensory deprivation. The most expansive was the now-notorious MKUltra project, which used (sometimes unwitting) American and Canadian citizens as test subjects in a wide-ranging research program on mind control. As McCoy notes, the CIA dispensed $25 million for psychological experiments on human subjects to researchers at non-governmental organizations, including 44 universities and 12 hospitals. The chilling outcome of this research was made public only after *The New York Times* published an exposé on U.S. involvement in torture and assassinations in Honduras, and the CIA was forced to release the interrogation training manual known as KUBARK. Dated 1963, the last year of the MKUltra program, KUBARK details interrogation methods that include periods of both sensory overstimulation and sensory deprivation.

Researchers now recognize that many of the dramatic effects of Hebb's research were not the result of reduced stimulus, per se, but to monotonously repeated overstimulation: the lighted visor, the white noise, even the pressure of the bed against the back. But the study became recognized as a landmark investigation into sensory deprivation. And sensory deprivation continues to be associated with torture, obscuring the fact that dramatic negative effects such as hallucinations, intense anxiety, and mental breakdown are not

NASA

merely a result of restricted sensation, but of how sensation is manipulated and under what circumstances.

I AM RELUCTANT TO ADMIT IT, but some corner of my mind was vigilant for the onset of hallucinations. For regression and psychological breakdown. For the dissolution of the self into nothing.

I try to relax. Breathe slower and deeper. I try to release the tension in my legs and arms, to let my head drop into the water as it might drop onto a pillow. This is harder than you might think. My neck stretches a tiny bit longer. My head drops a fraction of an inch. And then I am stuck. Focusing on my shoulders, I think, *relax*. The tension maintains a vice grip. *Goddamnit*, I think, *relax*.

What I did not expect: once I stopped trying so hard to relax, my attention turned inward, burrowing through bodily sensation like geological layers of sediment. I become aware of the curve and stretch of each muscle, the pull of tendon and ligament. I notice the meat of my upper arms as distinct strips of flesh around a solid core of humerus. I feel my ribs as what they are, a bone case for my organs. Cosmonaut of my own anatomy, I go deeper and become aware of stomach and gut, the spaces carved out for food and waste and fetus, all of it pulsing as the bone case yawns open, then draws shut, with every breath. How have I never noticed all this, before?

WAIT, DID I FALL ASLEEP? I am suddenly aware of myself as a pinprick consciousness in a vast dark, where before I was not, which makes me wonder if I have just woken up. How long have I been in the tank?

My right shoulder twitches. My right forearm. My left calf muscle. It's like those involuntary muscle twitches you get right before you fall asleep. Except that I'm not falling asleep, I'm waking up. Or letting go. This body doesn't seem to belong to me. Muscles are releasing like the first raindrops of a quickening spring shower. It is both exhilarating and utterly relaxing. I'm not trying to do anything, anymore. I'm watching.

Here, beyond conscious control, is the previously unattainable physical release. My shoulders go. My neck relaxes. The muscles along my spine elongate and a subtle ache lodged in my back for months finally disappears. I can't remember the last time I felt this good.

But how can I describe this other feeling, being utterly present while also being outside my body and outside time? Of being connected to everything and nothing?

The only way I can describe it is that floating feels like being meditated. As if the tank does it for you, from the outside in.

THE AVERAGE BRAIN IS an electrochemical organ that generates as much as 10 watts of electricity, enough to power a small light bulb. This electrical activity can be recorded in the form of brainwaves that have higher or lower frequencies and amplitudes, and the four most common—beta, alpha, theta, and delta—roughly indicate levels of arousal. Beta waves are short and fast and associated with day-to-day levels of activity, such as reading a book or navigating a busy city street. On the other end of the spectrum, delta waves are long and slow, associated with deep sleep. It's the grey areas in the middle that seem to be at play in flotation.

EEG recordings have shown that during flotation beta and alpha waves decrease, while theta waves increase, patterns of brain activity typically associated with sleep or meditative states. While there are different distributions of brainwaves across different brain areas, decreasing beta and alpha waves are broadly associated with lowering states of arousal. And while theta waves occur throughout the brain during wakefulness, they characterize the first stage of sleep. Coupled with subjective reports about flotation, these patterns point toward a hypnogogic state, that liminal zone where conscious control of mental processes begins to loosen its grip, when you stop engaging with the outside world and turn inward, just before falling asleep. The first flotation tank was built in the mid-1950s by a researcher who had a lifelong fascination with states of consciousness. John Lilly, a brilliant and wildly unorthodox researcher then studying sensory deprivation at the National Institute of Mental Health (NIMH), invented an upright flotation tank in which a subject could be fully submerged like a scuba diver. The suit he designed is reminiscent of scuba gear, with the addition of a rather terrifying-looking hood and blackout mask to restrict vision (see Just Relax).

At first, Lilly experimented on himself and fellow researchers, and he quickly realized the discomfort of the hood and the fear of drowning were aggravating distractions. He decided to ditch the suit and redesign the tank so a subject could float horizontally, with their face out of the water.

Lilly, who was friends with such luminaries as Richard Feynman and Buckminster Fuller, lost a great deal of credibility in the scientific community when he left NIMH to follow his own dubious research programs, which included taking massive amounts of LSD and Ketamine (sometimes while floating), giving LSD to dolphins, and trying to communicate with extraterrestrial life. "I took LSD for the first time, in the tank, with three dolphins under it in a sea pool. I was scared shitless," wrote Lilly. "As I climbed over the wall into the saltwater, a memorandum, from N.I.M.H appeared before me: 'Never take LSD alone.' That's when I learned that fear can propel you in a rocketship to far out places." And yet, Lilly may have been on to something.

Subsequent research suggests there are states of arousal that fall between conventionally categorized states such as sleep and waking, supporting his intuition that there are multiple states of human consciousness we have yet to fully explore. In the 1990s, the discovery of the Default Mode Network, an interconnected archipelago of brain areas whose activity decreases when we are focused on a task and increases when we stop focusing, complicated the notion that brain areas are either "on" or "off," in use or on hold. And sleep, as anyone who has used the popular Sleep-Cycle app knows, is composed of multiple levels of arousal serving many functions, which we have yet to fully understand. As veteran REST researcher Roderick Borrie puts it, "If you just look at brainwaves, it looks like the brain is asleep, but it's not, which allows a different kind of processing to occur."

"We had a Zen master come to my lab once," Suedfeld told me, "and he asked us if we would let him float, so we did, of course. He came out and said, every day since I was very young, I meditate four or five hours a day, and the level of meditative depth that I experienced in the tank was such as I can only manage maybe once or twice a year." Suedfeld, who coined the term REST with Borrie in the 1970s, has shown that restricted stimulus environments can reduce pain, ease headaches, and support behavior modification. Recently,

Just Relax

Early experiments with sensory deprivation provoked fear and anxiety in test subjects. John Lilly had people don a mask with blackout goggles and breathing tubes (top image), then submerge themselves completely underwater.

Donald Hebb used a visor, padding around the ears, and cuffs from the elbow past the fingertips to prevent sensory stimulation (below).

he has used REST to help people quit smoking. He believes REST has clinical advantages over meditation. "You don't have to learn how to do it," he said. "You are in no danger of becoming addicted physically and you can't overdose. If you have a bad experience all you have to do is get up and walk out."

Highly experienced meditators show dramatic increases and synchronization in gamma waves, a type of brainwave even shorter and faster than beta waves, which have not been found in the brain during flotation. As Richard Davidson, a meditation researcher at the University of Madison-Wisconsin, put it, "Meditation is really designed to produce awakening, not sleep." And there are many different meditation techniques. "Meditation is kind of like sports, some are more active, some are less active." When I asked about mindfulness meditation, the practice most commonly compared to flotation, he said, "Mindfulness is classically described as paying attention non-judgmentally, and I doubt that participants in REST are given that instruction."

Evidence for what happens during flotation remains elusive partly because after the 1960s, sensory deprivation was something of a dirty word, associated with Lilly's less-than-scientific experimentation and the torture of political prisoners both at home and abroad. The research dissipated. "Hebb and others who were doing that kind of research were attacked as being complicit in torture," said Suedfeld. He paused. "I know of several people doing that research who were physically attacked. One had his children threatened at school. They had their houses and automobiles vandalized, et cetera. So that drove quite a few people out of the field, not surprisingly." Even today, the REST literature is plagued by small sample sizes, poor controls, and case studies that offer tantalizing, if incomplete, evidence.

But research may be picking up, due partly to the recent resurgence of commercial float centers like the one I visited in Chelsea, or the one recently installed in a yoga studio just 20 blocks uptown. In Sweden, researchers such as Annette Kjellgren, Sven Bood, and Torsten Norlander have been conducting larger, well-controlled studies that show REST is clinically effective on conditions such as stress, chronic pain, and hypertension. In the U.S., Justin Feinstein, a young clinical neuropsychologist at the Laureate Institute for Brain Research, is constructing a flotation lab that will, for the first time, allow investigation into changes in brain activity during flotation. He will use the Institute's two fMRI scanners to record brain activity while subjects are floating. Once Feinstein's lab is up and running, it will be one of only a few flotation research labs in the country, and the only one with fMRI scanning capability. "A lot of speculation goes on in the field," he said, "but we just don't know. A lot of this research has yet to be done."

One of the biggest remaining mysteries is why people tend to have a similar progression of subjective experiences in the tank. Thomas Fine at the University of Toledo's College of Medicine, whose research has shown that REST raises endorphins and lowers stress hormones, as well as offering relief from hypertension, rheumatoid arthritis, and pain, has encountered this progression many times in his work. He notes that people will have different experiences depending on different individual characteristics, such as sensitivity to external stimuli, but says, "Even John Lilly talked about people initially being aware of their body and the effect on the body, then when people got used to the tank, it was less about their body and more about their internal experience. It could be more about emotion or what their thoughts are, or the connection between those. Then as they float further, they go to no thought, just experience. That's the level we think is related to the deep relaxation."

WAS I WAITING FOR an out-of-body experience? For enlightenment?

Did I expect the private present tense to be so deafening? And then so quiet? When I stopped trying so hard to relax, what came over me was a calm more profound than anything I could have imagined.

I did not expect this, either: Once I was less distracted by the physical, my attention turned toward the mental, peeling back layer after layer of thought toward some white-hot core of emotion. When I began to cry, softly, the water responded, creating tiny wavelets that rocked my body at the center of the tank.

Near the end of my float, I noticed a new sound, soft and slightly distant. Not bothersome, but a constant hum with a flickering texture. I concentrated on this sound. Listened. Tried to name it. The best I could come up with was crickets. It sounded like a chirruping field of crickets, just across a two-lane road on a summer evening. It was lovely. Mesmerizing.

Afterward, when I asked Zeiger about the crickets, he nodded and said, "That's the sound of your consciousness at work." Zeiger had a tall glass of spicy iced tea waiting for me in his living room. It was the best thing I have ever tasted, which I know because I wrote this in my notebook—"the best thing I have ever tasted." He sat across from me in an expensive ergonomic desk chair, wearing a pale blue shirt that matched his jeans and steady blue eyes, and all that undifferentiated blue made looking at him like looking at the sky—my eyes didn't quite know where to focus.

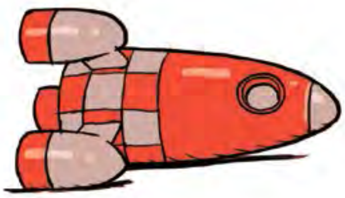
I felt raw. A little dazed. Colors were a bit overwhelming. They say your senses are heighted afterward. As I blinked at Zeiger, trying to follow what he was saying, I was reminded that the sensory reduction techniques used by the CIA were designed to make prisoners more sensitive to the overstimulation that follows. At Guantanamo Bay, they have used bright lights and blared heavy metal from loudspeakers for days.

Outside, on West 23rd Street, everything was too bright, too loud, too fast. Text screamed from all sides. Signs for "News on 23rd" and takeout from "Wrapido." A woman with short legs ran for a bus, and I watched her watch it pull away. In its wake, an old brick building with huge white letters in each window: "Joschi Yoga." I thought about all the people inside, stretching and sweating and trying to calm their minds. A siren shrieked into life somewhere down the avenue, wailing high and bright.

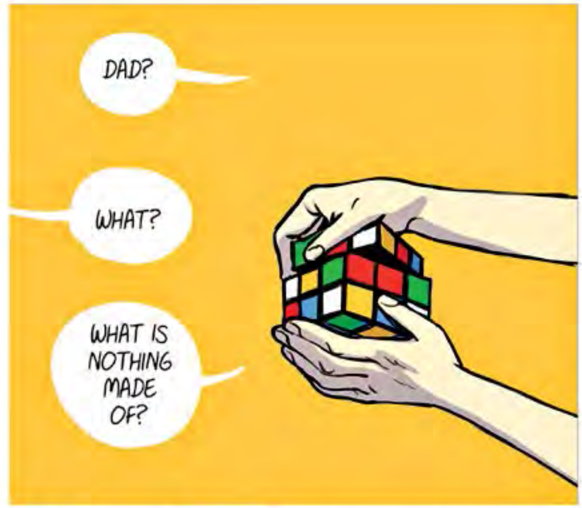
MEEHAN CRIST is writer-in-residence in Biological Sciences at Columbia University and editor-at-large at *Nautilus*. Her writing has appeared in publications such as *The New York Times, The Los Angeles Times, The New Republic, The Believer, Scientific American,* and *Science*.

A Complicated Question

A child asks, and war answers



BY ASAF HANUKA

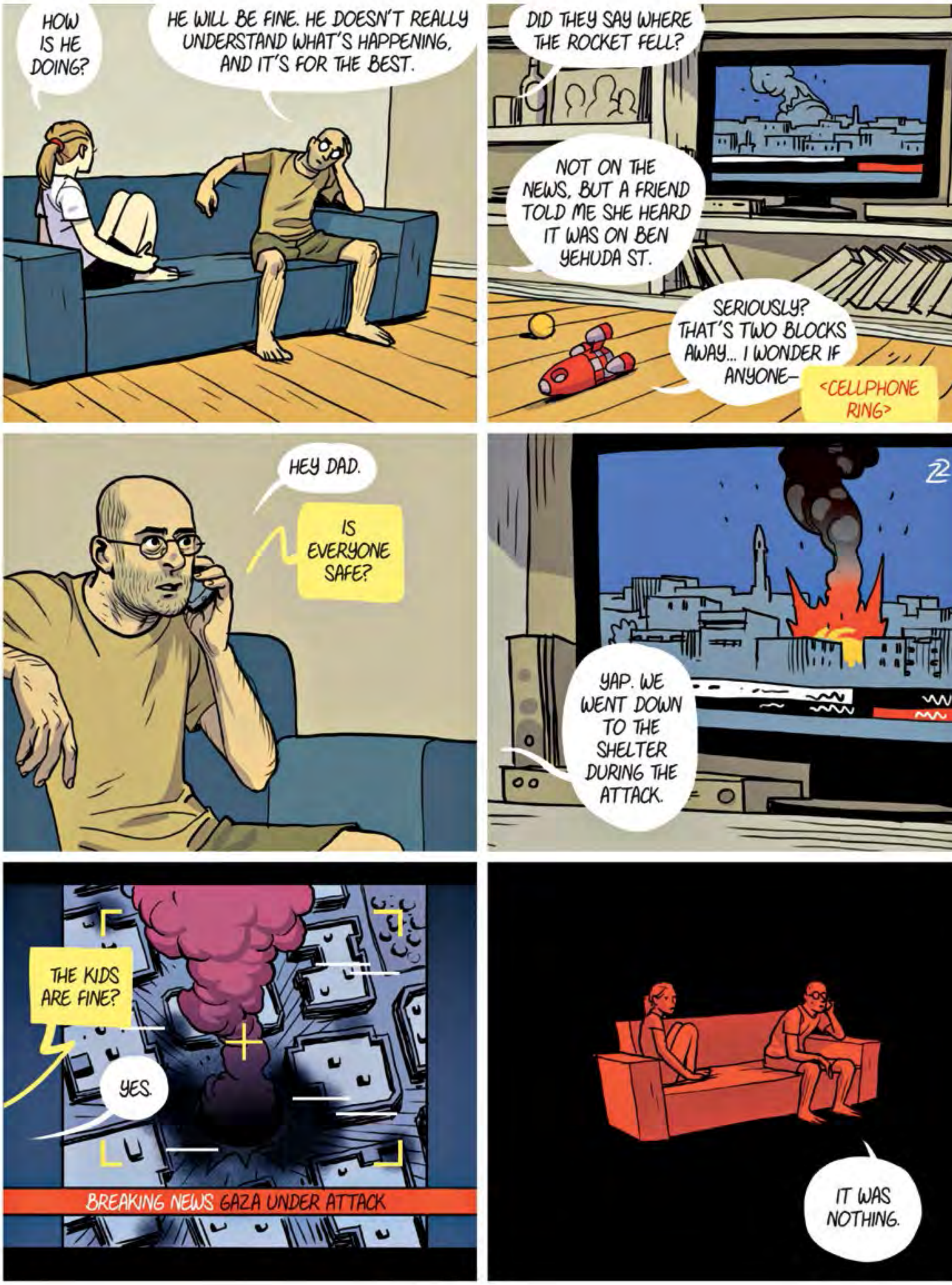



LATER THAT DAY
LET'S SEE, N-O-T-H-I-N-G
HMMM... "UNIVERSE FROM NOTHING", SOUNDS INTERESTING, IT MIGHT BE WHAT I'M LOOKING FOR.
Lawrence M. Krauss (2014) "Universe from NOTHING!" [FULL]
Lawrence Krauss
Subscribe
EMPTY SPACE IS A BOILING, BUBBLING BREW OF VIRTUAL PARTICLES THAT POP IN AND OUT OF EXISTENCE IN A TIME SCALE SO SHORT THAT YOU CAN'T EVEN MEASURE THEM.
EVERY ATOM IN YOUR BODY CAME FROM A STAR THAT EXPLODED... YOU ARE ALL STARDUST.
IT'S POETIC, BUT I STILL DON'T UNDERSTAND WHAT NOTHING'S MADE OF.
MAYBE THIS ONE...
Alan Watts - On Nothingness
Mark Watts
Subscribe
BUT THE MISTAKE IN THE BEGINNING WAS TO THINK OF SOLIDS AND SPACE AS TWO DIFFERENT THINGS, INSTEAD OF AS TWO ASPECTS OF THE SAME THING.
THIS IS REALLY DEEP BUT I STILL DON'T GET IT.
<CELLPHONE RING>

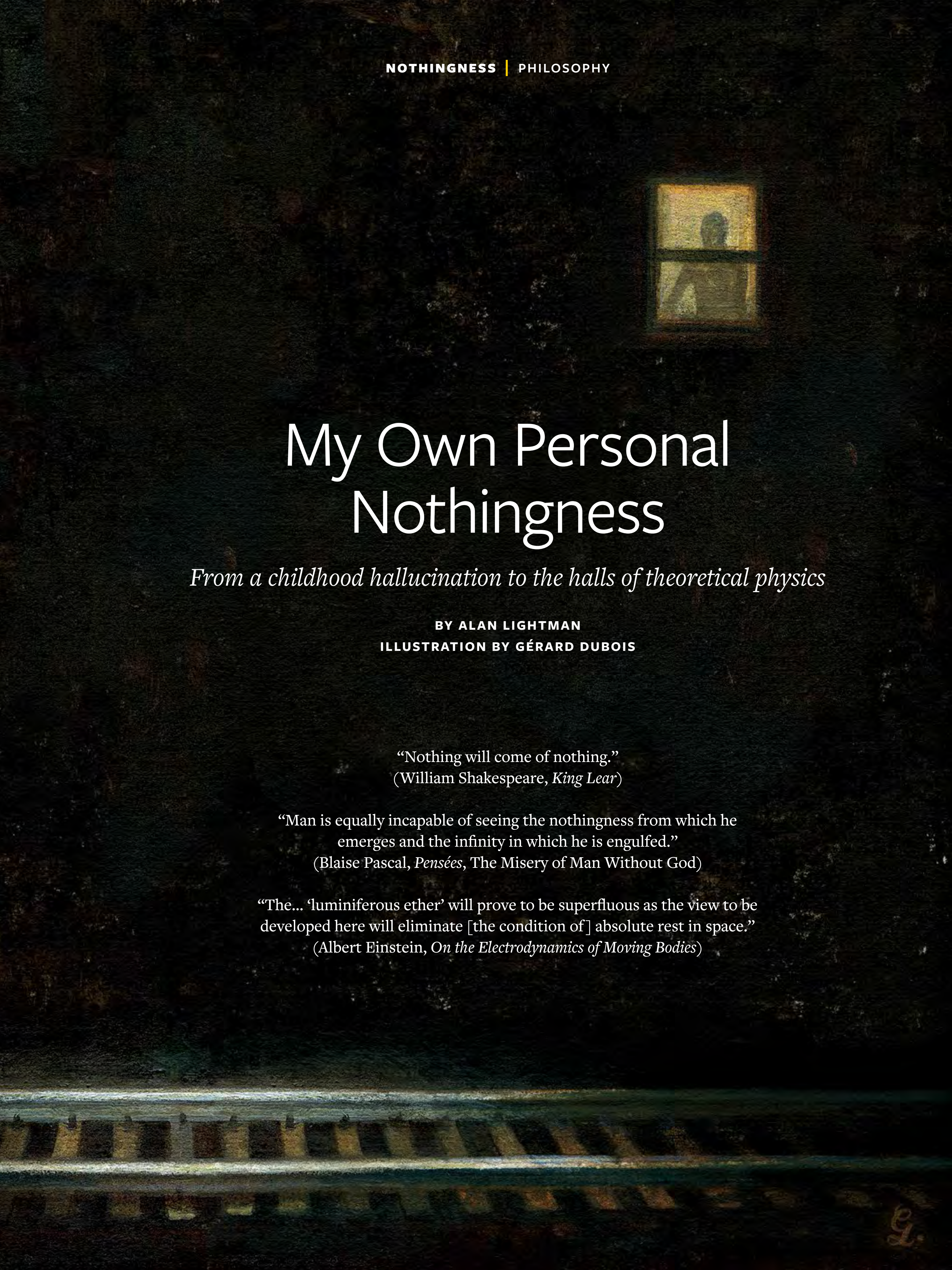

HEY HON, WHAT'S UP?
WHERE ARE YOU? WHAT ARE YOU DOING?
I'M AT THE STUDIO, DOING NOTHING. WHY?
THE IDF CALLED UP THOUSANDS OF RESERVISTS... ROCKETS OVER ASHDOD AND ASHKELON... THEY SAY THERE IS A POSSIBLE ATTACK ON TEL AVIV TODAY, AT 20:00.
OH NO...
WE'RE READY.


20:00
DAD, I'M SCARED.
YOU HAVE NOTHING TO WORRY ABOUT. ONCE THE SIREN STARTS WE WILL GO DOWN QUIETLY TO THE SHELTER LIKE WE DISCUSSED. EVERYTHING WILL BE FINE. NOTHING WILL HAPPEN TO US.
HOW DO YOU KNOW?
BECAUSE THE ARMY HAS ROCKETS THAT SHOOT THE BAD ROCKETS AIMING TO HURT US.
SO WHY DO WE HAVE TO GO TO THE SHELTER?
SWEETIE, JUST—
BOOM


THAT MUST HAVE BEEN CLOSE.
YOU THINK IT'S SAFE TO GO BACK UP?
LET'S WAIT 10 MORE MINUTES.
LATER THAT NIGHT
YOU PROMISED TO TELL WHAT IS NOTHING MADE OF.
I KNOW, I EVEN WENT ON THE INTERNET TO LOOK IT UP.
DID YOU FIND OUT?
IT'S A COMPLICATED QUESTION THAT HAS DIFFERENT ANSWERS. IT DEPENDS WHO YOU ASK.
I ASK YOU.
OK... NOTHING ISN'T MADE OF ANYTHING. IT'S AN IDEA THAT HELPS US UNDERSTAND WHAT IT MEANS TO HAVE SOMETHING.
I STILL DON'T GET IT.
LOOK, IT'S A RELATIVE TERM...
LIKE A COUSIN?
EXACTLY, "NOTHING" IS A COUSIN OF "SOMETHING". THEY ARE OPPOSITE IDEAS THAT NEED EACH OTHER TO MAKE SENSE.
YOU THINK MY COUSIN JONATHAN WENT DOWN TO THE SHELTER LIKE WE DID?
I'M SURE HE DID.
WE WILL CALL HIM TOMORROW OK?
'NIGHT DAD.



ASAF HANUKA is an Israeli illustrator and comic book artist, notable for his autobiographical comic series, "The Realist." He is twin brother to illustrator Tomer Hanuka, with whom he co-created "Bipolar," an experimental comic book series that was nominated for the Ignatz awards.



My Own Personal Nothingness

From a childhood hallucination to the halls of theoretical physics

BY ALAN LIGHTMAN
ILLUSTRATION BY GÉRARD DUBOIS

"Nothing will come of nothing."
(William Shakespeare, *King Lear*)

"Man is equally incapable of seeing the nothingness from which he emerges and the infinity in which he is engulfed."
(Blaise Pascal, *Pensées*, The Misery of Man Without God)

"The… 'luminiferous ether' will prove to be superfluous as the view to be developed here will eliminate [the condition of] absolute rest in space."
(Albert Einstein, *On the Electrodynamics of Moving Bodies*)

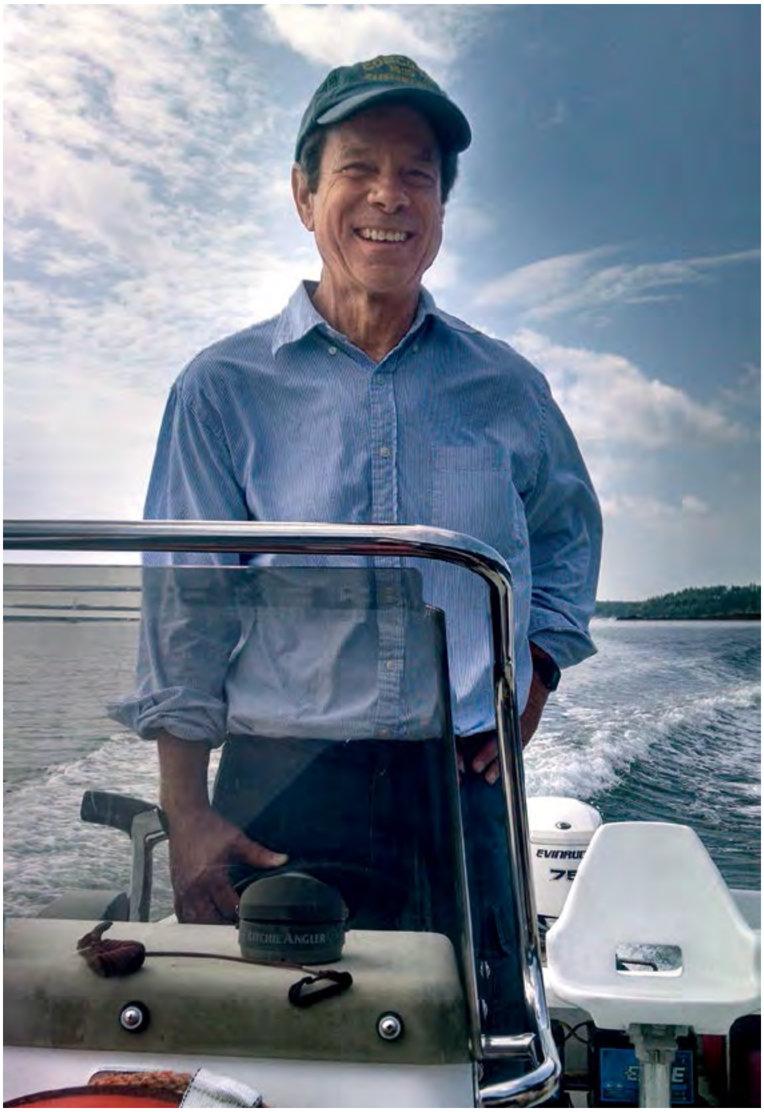
MY MOST VIVID ENCOUNTER with Nothingness occurred in a remarkable experience I had as a child of 9 years old. It was a Sunday afternoon. I was standing alone in a bedroom of my home in Memphis, Tennessee, gazing out the window at the empty street, listening to the faint sound of a train passing a great distance away, and suddenly I felt that I was looking at myself from outside my body. I was somewhere in the cosmos. For a brief few moments, I had the sensation of seeing my entire life, and indeed the life of the entire planet, as a brief flicker in a vast chasm of time, with an infinite span of time before my existence and an infinite span of time afterward. My fleeting sensation included infinite space. Without body or mind, I was somehow floating in the gargantuan stretch of space, far beyond the solar system and even the galaxy, space that stretched on and on and on. I felt myself to be a tiny speck, insignificant in a vast universe that cared nothing about me or any living beings and their little dots of existence, a universe that simply was. And I felt that everything I had experienced in my young life, the joy and the sadness, and everything that I would later experience, meant absolutely nothing in the grand scheme of things. It was a realization both liberating and terrifying at once. Then, the moment was over, and I was back in my body.

The strange hallucination lasted only a minute or so. I have never experienced it since. Although Nothingness would seem to exclude awareness along with the exclusion of everything else, awareness was part of that childhood experience, but not the usual awareness I would locate within the three pounds of gray matter in my head. It was a different kind of awareness. I am not religious, and I do not believe in the supernatural. I do not think for a minute that my mind actually left my body. But for a few moments I did experience a profound absence of the familiar surroundings and thoughts we create to anchor our lives. It was a kind of Nothingness.

TO UNDERSTAND ANYTHING, as Aristotle argued, we must understand what it is not, and Nothingness is the ultimate opposition to any thing. To understand matter, said the ancient Greeks, we must understand the "void," or the absence of matter. Indeed, in the fifth century B.C., Leucippus argued that without the void there could be no motion because there would be no empty spaces for matter to move into. According to Buddhism, to understand our ego we must understand the ego-free state of "emptiness," called *śūnyatā*. To understand the civilizing effects of society, we must understand the behavior of human beings removed from society, as William Golding so powerfully explored in his novel *Lord of the Flies*.

Following Aristotle, let me say what Nothingness is not. It is not a unique and absolute condition. Nothingness means different things in different contexts. From the perspective of life, Nothingness might mean death. To a physicist, it might mean the complete absence of matter and energy (an impossibility, as we will see), or even the absence of time and space. To a lover, Nothingness might mean the absence of the beloved. To a parent, it might mean the absence of children. To a painter, the absence of color. To a reader, a world without books. To a person impassioned with empathy, emotional numbness. To a theologian or philosopher like Pascal, Nothingness meant the timeless and spaceless infinity known only by God. When King Lear says to his daughter Cordelia, "Nothing will come of nothing," he means that she will receive far less of his kingdom than her two fawning sisters unless she can express her boundless love for him. The second "nothing" refers to Cordelia's silence contrasted with her

PHOTO BY MICHAEL SEGAL



THE COMMUTE Alan Lightman en route to his summer home off the coast of Maine.

sisters' gushing adoration, while the first is her impending one-room shack compared to their opulent palaces.

Although Nothingness may have different meanings in different circumstances, I want to emphasize what is perhaps obvious: All of its meanings involve a comparison to a material thing or condition we know. That is, Nothingness is a relative concept. We cannot conceive of anything that has no relation to the material things, thoughts, and conditions of our existence. Sadness, by itself, has no meaning without reference to joy. Poverty is defined in terms of a minimum income and standard of living. The sensation of a full stomach exists in comparison to that of an empty one. The sensation of Nothingness I experienced as a child was a contrast to feeling centered in my body and in time.

MY FIRST EXPERIENCE WITH Nothingness in the material world of science occurred when I was a graduate student in theoretical physics at the California Institute of Technology. In my second year, I took a formidable course with the title of Quantum Field Theory, which explained how all of space is filled up with "energy fields," usually called just "fields" by physicists. There is a field for gravity and a field for electricity and magnetism, and so on. What we regard as physical "matter" is the excitation of the underlying fields. A key point is that according to the laws of quantum physics, all of these fields are constantly jittering a bit—it is an impossibility for a field to be completely dormant—and the jittering causes subatomic particles like electrons and their antiparticles, called positrons, to appear for a brief moment and then disappear again, even when there is no persistent matter. Physicists call a region of space with the lowest possible amount of energy in it the "vacuum." But the vacuum cannot be free of fields. The fields necessarily permeate all space. And because they are constantly jittering, they are constantly producing matter and energy, at least for brief periods of time. Thus the "vacuum" in modern physics is not the void of the ancient Greeks. The void does not exist. Every cubic centimeter of space in the universe, no matter how empty it seems, is actually a chaotic circus of fluctuating fields and particles flickering in and out of existence on the subatomic scale. Thus, at the material level, there is no such thing as Nothingness.

Remarkably, the active nature of the "vacuum" has been observed in the lab. The principal example lies in the energies of electrons in hydrogen atoms, which can be measured to high accuracy by the light they emit. According to quantum mechanics, the electric and magnetic field of the vacuum is constantly producing short-lived pairs of electrons and positrons. These ghostlike particles pop out of the vacuum into being, enjoy their lives for about one-billionth of one-billionth of a second, and then disappear again.

In an isolated hydrogen atom, surrounded by seemingly empty space, the proton at the center of the atom draws the fleeting vacuum electrons toward it and repulses the vacuum positrons, causing its electrical charge to be slightly reduced. This reduction of the proton's charge, in turn, slightly modifies the energy of the orbiting (non vacuum) electrons in a process called the Lamb shift, named after physicist Willis Lamb and first measured in 1947. The measured shift in energy is quite small, only three parts in 100 million. But it agrees very closely with the complex equations of the theory—a fantastic validation of the quantum theory of the vacuum. It is a triumph of the human mind to understand so much about empty space.

The concept of empty space—and Nothingness—played a major role in modern physics even before our understanding of the quantum vacuum. According to findings in the mid 19th century, light is a traveling wave of electromagnetic energy, and it was conventional wisdom that all waves, such as sound waves and water waves, required a material medium to carry them along. Take the air out of a room, and you will not hear someone speaking. Take the water out of a lake, and you cannot make waves. The material medium hypothesized to convey light was a gossamer substance called the "ether." Because we can see light from distant stars, the ether had to fill up all space. Thus, there was no such thing as empty space. Space was filled with the ether.

In 1887, in one of the most famous experiments in all of physics, two American physicists at what is now Case Western Reserve University in Cleveland, Ohio attempted to measure the motion of the earth through the ether. Their experiment failed. Or rather, they could not detect any effects of the ether. Then, in 1905, the 26-year-old Albert Einstein proposed that the ether did not exist. Instead, he hypothesized that light, unlike all other waves, could propagate through completely empty space. All this was before quantum physics.

That denial of the ether, and hence embrace of a true emptiness, followed from a deeper hypothesis of the young Einstein: There is no condition of absolute rest in the cosmos. Without absolute rest, there cannot be absolute motion. You cannot say that a train is moving at a speed of 50 miles per hour in any absolute sense. You can say only that the train is moving at 50 miles per hour relative to another object, like a train station. Only the relative motion between two objects has any meaning. The reason Einstein did away with the ether is because it would have established a reference frame of absolute rest in the cosmos. With a material ether filling up all space, you could say whether an object is at rest or not, just as you can say whether a boat in a lake is at rest or in motion with respect to the water. So, through the work of Einstein, the idea of material emptiness, or Nothingness, was connected to the rejection of absolute rest in the cosmos. In sum, first there was the ether filling up all space. Then Einstein removed the ether, leaving truly empty space. Then other physicists filled space again with quantum fields. But quantum fields do not restore a reference frame of absolute rest because they are not a static material in space. Einstein's principle of relativity remained.

One of the pioneers of quantum field theory was the legendary physicist Richard Feynman, a professor at Caltech and a member of my thesis committee. In the late 1940s, Feynman and others developed the theory of how electrons interact with the ghostly particles of the vacuum. Earlier in that decade, as a cocky young scientist, he had worked on the Manhattan Project. By the time I knew him at Caltech, in the early 1970s, Feynman had mellowed a bit but was still ready to overturn received wisdom at the drop of a hat. Every

Sadness, by itself, has no meaning without reference to joy.

day, he wore white shirts, exclusively white shirts, because he said they were easier to match with different colored pants, and he hated to spend time fussing about his clothes. Feynman also had a strong distaste for philosophy. Although he had quite a wit, he viewed the material world in a highly straightforward manner, without caring to speculate on the purely hypothetical or subjective. He could and did talk for hours about the behavior of the quantum vacuum, but he would not waste a minute on philosophical or theological considerations of Nothingness. My experience with Feynman taught me that a person can be a great scientist without concerning him or herself with questions of "Why," which fall beyond the scientifically provable.

However, Feynman did understand that the mind can create its own reality. That understanding was revealed in the Commencement address he gave at my graduation from Caltech in 1974. It was a boiling day in late May, outdoors of course, and we graduates were all sweating heavily in our caps and gowns. In his talk, Feynman made the point that before publishing any scientific results, we should think of all the possible ways that we could be wrong. "The first principle" he said, "is that you must not fool yourself—and you are the easiest person to fool."

IN THE WACHOWSKI BROTHERS' landmark film *The Matrix* (1999), we are well into the drama before we realize that all the reality experienced by the characters—the pedestrians walking the streets, the buildings and restaurants and night clubs, the entire cityscape—is an illusion, a fake movie played in the brains of human beings by a master computer. Actual reality is a devastated and desolate planet, in which human beings are imprisoned, comatose, in leaf-like pods and drained of their life energy to power the machines. I would argue that much of what we call reality in our lives is also an illusion, and that we are much closer to dissolution, and Nothingness, than we usually acknowledge.

Let me explain. A highly unpleasant idea, but one that has been accepted by scientists over the last couple of centuries, is that we human beings, and all living beings, are completely material. That is, we are made of material atoms, and only material atoms. To be precise, the average human being consists of about 7×10^{27} atoms (7,000 trillion trillion atoms)—65 percent oxygen, 18 percent carbon, 10 percent hydrogen, 3 percent nitrogen, 1.4 percent calcium, 1.1 percent phosphorous, and traces of 54 other chemical elements. The totality of our tissues and muscles and organs and brain cells is composed of these atoms. And there is nothing else. To a vast cosmic being, each of us would appear to be an assemblage of atoms. To be sure, it is a special assemblage. A rock does not behave like a person. But the mental sensations we experience as consciousness and thought are purely material consequences of the purely material electrical and chemical interactions between neurons, which in turn are simply assemblages of atoms. And when we die, this special assemblage disassembles. The total number of atoms in our body at our last breath remains constant. Each atom could be tagged and tracked as it subsequently mingled with air and water and soil. The material would remain, scattered about. Each of us is a temporary assemblage of atoms, not more and not less. We are all on the verge of material disassemblage and dissolution.

All that having been said, the sensation of consciousness is so powerful and compelling that we endow other human beings—i.e., certain other assemblages of atoms—with a transcendent quality, some nonmaterial and magnificent essence. And as the assemblage of atoms most important to each of us is our own self, we endow ourselves with a transcendent quality—a self, an ego, an "I-ness"—that blooms far larger and more significant than merely a collection of atoms.

Likewise, our human-made institutions. We endow our art and our cultures and our codes of ethics and our laws with a grand and everlasting existence. We give these institutions an authority that extends far beyond ourselves. But in fact, all of these are constructions of our minds. That is, these institutions and codes and their imputed meanings are all consequences of exchanges between neurons, which in turn are simply material atoms. They are all mental constructions. They have no reality other than that which we give them, individually and collectively.

The Buddhists have understood this notion for centuries. It is part of the Buddhist concepts of emptiness and impermanence. The transcendent, nonmaterial, long-lasting qualities that we impart to other human beings and to human institutions are an illusion, like the computer-generated world in *The Matrix*. It is certainly true that we human beings have achieved what, to our minds, is an extraordinary accomplishment. We have scientific theories that can make accurate predictions about the world. We have created paintings and music and literature that we consider beautiful and meaningful. We have entire systems of laws and social codes. But these things have no intrinsic value outside of our minds. And our minds are a collection of atoms, fated to disassemble and dissolve. And in that sense, we and our institutions are always approaching Nothingness.

So where do such sobering thoughts leave us? Given our temporary and self-constructed reality, how should we then live our lives, as individuals and as a society? As I have been approaching my own personal Nothingness, I have mulled these questions over quite a bit, and I have come to some tentative conclusions to guide my own life. Each person must think through these profound questions for him or herself—there are no right answers. I believe that as a society we need to realize we have great power to make our laws and other institutions whatever we wish to make them. There is no external authority. There are no external

> "The first principle" Feynman said, "is that you must not fool yourself—and you are the easiest person to fool."

limitations. The only limitation is our own imagination. So, we should take the time to think expansively about who we are and what we want to be.

As for each of us as individuals, until the day when we can upload our minds to computers, we are confined to our physical body and brain. And, for better or for worse, we are stuck with our personal mental state, which includes our personal pleasures and pains. Whatever concept we have of reality, without a doubt we experience personal pleasure and pain. We feel. Descartes famously said, "I think, therefore I am." We might also say, "I feel, therefore I am." And when I talk about feeling pleasure and pain, I do not mean merely physical pleasure and pain. Like the ancient Epicureans, I mean all forms of pleasure and pain: intellectual, artistic, moral, philosophical, and so on. All of these forms of pleasure and pain we experience, and we cannot avoid experiencing them. They are the reality of our bodies and minds, our internal reality. And here is the point I have reached: I might as well live in such a way as to maximize my pleasure and minimize my pain. Accordingly, I try to eat delicious food, to support my family, to create beautiful things, and to help those less fortunate than myself because those activities bring me pleasure. Likewise, I try to avoid leading a dull life, to avoid personal anarchy, and to avoid hurting others because those activities bring me pain. That is how I should live. A number of thinkers far deeper than I, most notably the British philosopher Jeremy Bentham, have come to these same conclusions via very different routes.

What I feel and I know is that I am here now, at this moment in the grand sweep of time. I am not part of the void. I am not a fluctuation in the quantum vacuum. Even though I understand that someday my atoms will be scattered in soil and in air, that I will no longer exist, that I will join some kind of Nothingness, I am alive now. I am feeling this moment. I can see my hand on my writing desk. I can feel the warmth of the sun through the window. And looking out, I can see the pine-needled path that goes down to the sea. Now.

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The Bridge From Nowhere

How is it possible to get something from nothing?

BY AMANDA GEFTER

THE QUESTION OF BEING is the darkest in all philosophy." So concluded William James in thinking about that most basic of riddles: How did something come from nothing? The question infuriates, James realized, because it demands an explanation while denying the very possibility of explanation. "From nothing to being there is no logical bridge," he wrote.

In science, explanations are built of cause and effect. But, if nothing is truly nothing, it lacks the power to cause. It's not simply that we can't find *the right* explanation—it's that *explanation itself* fails in the face of nothing.

This failure hits us where it hurts. We are a narrative species. Our most basic understanding comes through stories, and how something came from nothing is the ultimate story, the primordial narrative,

more fundamental than the hero's journey or boy meets girl. Yet it is a story that undermines the notion of story. It is a narrative woven of self-destruction and paradox.

How could it not be? It stars Nothing—a word that is a paradox by its mere existence as a word. It's a noun, a *thing*, and yet it is no thing. The minute we imagine it or speak its name, we spoil its emptiness with the stain of meaning. One has to wonder, then, is the problem with nothingness or is the problem with us? Is it cosmic or linguistic? Existential or psychological? Is this a paradox of physics or a paradox of thought?

Either way, here's the thing to remember: The solution to a paradox lies in the question, never in the answer. Somewhere there must be a glitch, a flawed assumption, a mistaken identity. In so succinct a question as "how did something come from nothing?" there aren't many places to hide. Perhaps that is why we return again and again to the same old ideas in new and improved guises, playing the trajectory of science like a fugue, or variations on a theme. With each pass, we try to lay another stepping stone in James' elusive bridge.

THE OLDEST STONE is this: If you can't get something from nothing, try making nothing less like nothing. The ancient Greeks suggested that empty space is filled with substance—a plenum, an ether. Aristotle conceived of the ether as an unchanging fifth element, more perfect and heavenly in its invariance than earth, air, fire, or water. True nothingness was at odds with Aristotle's physics, which said that bodies rise up or fall down as dictated by their rightful place in the natural order of things. Nothingness, however, would be perfectly symmetric—it would look the same from every angle—rendering absolute spatial directions like "up" and "down" utterly meaningless. An ether, Aristotle figured, could serve as a kind of cosmic compass, an ultimate reference frame against which all motion could be measured. For those who abhorred a vacuum, the ether banished every last trace of it.

The ancient ether stuck around for millennia until it was reimagined in the late 19th century by physicists like James Clerk Maxwell, who discovered that light behaves as a wave that always travels at a particular speed. What was waving, and speed relative to what? The ether was a handy answer, providing both a medium for light waves to travel through, and, as Aristotle originally imagined, a reference frame against which all change in the universe would unfold. But when Albert Michelson and Edward Morley set out to measure the motion of the Earth through the "ether wind" in 1887, they couldn't find it. With his special theory of relativity, Einstein put the final nail in the coffin of the ether soon after.

For decades, we have looked at the ether as a historical oddity, a throwback. But it is harder to kill than we imagined. Today, it can be glimpsed in a new form: the Higgs field, which permeates the vacuum of empty space and whose excitation is the now-famous Higgs boson. The Higgs is what's known as a scalar field, the only experimentally verified specimen of its kind. That means it has only a single value at every point in space (unlike the field that describes light, which at every point has both a size and direction). That's important, because it means the field will look the same to any observer regardless of whether they are standing still or accelerating.

What's more, its quantum spin is zero, ensuring that it looks the same from every angle. Spin is a measure of how much you have to rotate a particle before it looks the same as when it started. Force-carrying particles (photons, gluons) have integer spin—rotations by 360 degrees will leave them unchanged. Matter particles (electrons, quarks) have half-integer spin, which means you'd have to rotate them twice, 720 degrees, before they're back to where they started. But the Higgs has zero spin. No matter how you rotate it, it always looks the same. Just like empty space. Symmetry equals invisibility.

Following Aristotle's intuition, physicists today conceive of nothing as the ultimate state of symmetry—a relentless sameness that precludes the differentiation one would need to define any "thing." Indeed, as physicists run the cosmic film in reverse, tracing deep history back in time, they see the disparate shards of reality reunite and coalesce into an ever-growing symmetry, a symmetry that signifies an origin—and a nothing.

The Higgs has become famous for giving elementary particles their mass, but this obscures its true meaning. After all, giving particles mass is easy—slow them down below the speed of light and, voilà, mass. The hard part is to give particles mass without breaking the primordial symmetry in the process. The Higgs

PGS 70-71: PHOTO BY BEN A. PRUCHNIE/GETTY IMAGES FOR PACE LONDON field achieves this remarkable feat by taking on a nonzero value even in its lowest energy state. Crouching in every corner of empty space sit 246 gigaelectronvolts of Higgs—only we'll never notice, because it's the same at every point. Only a scalar field could hide in plain sight and get away with it. But elementary particles notice. Every time a particle's mass breaks the symmetry of the universe, the Higgs is there, posing as empty space, repairing the damage. Constantly laboring in the shadows, the Higgs keeps the universe's original symmetry intact. One can understand (if not forgive) the journalist's inclination to wax religious about "the God particle"—even if Leon Lederman, who coined the reviled term, originally called it "the Goddamn particle" though his publisher wouldn't let it fly.

All this means that the Higgs field is closer to nothing than, say, Maxwell's notion of the ether. It is our latest paintbrush for coloring in the void. With its unusual symmetry, the Higgs functions as nothing's covert disguise—but it is not in itself nothing. It has structure; it interacts. The physical origin of its 246 gigaelectronvolts remains unknown. With the Higgs, we can approach the boundary with nothingness, but we cannot cross it.

IF MAKING NOTHING LESS like nothing doesn't answer the question "how did something come from nothing," perhaps we ought to make cause less like a cause. This, too, has a history. The sudden appearance of maggots in the presence of rotting meat led to a widespread belief in spontaneous generation in the time of Aristotle; the breath of life could materialize from thin air. The boundary between nothing and something was shared with the one between life and death, spirit and matter, God and earth. This in turn brought to bear the whole complex of religion and faith, making for a rather comprehensive answer to our paradox. We accepted this theory for some 2,000 years, until it was dispelled by the microbiologist Louis Pasteur in 1864. *Omne vivum ex vivo*—all life from life. In the decades that followed, we saw spontaneous generation as yet another historical oddity. But, like the ether, today it is back again, wearing the sheep's clothing of quantum fluctuations.

Wrought by uncertainty, quantum fluctuations are effects without causes, the noise beneath the signal, a primeval static, random to the bone. The rules of quantum mechanics allow—actually, *require*—energy (and, by $E=mc^2$, mass) to appear "out of nowhere," from nothing. *Creation ex nihilo*—or so it seems.

Heisenberg's Uncertainty Principle is a natural source of quantum maggots. It says that certain pairs of physical features—position and momentum, energy and time—are bound together by a fundamental indeterminacy, so that the more accurately we specify one, the more ambiguous becomes the other. Together they form what's known as a conjugate pair, and together they preclude the existence of nothingness. Home in on a spatial position and momentum will fluctuate wildly to compensate; specify smaller, more precise quantities of time and energy will vacillate across a wider swath of improbable values. In the shortest eye blinks, across the smallest distances, whole universes can boil up into existence, then disappear. Zoom in

Heisenberg's Uncertainty Principle is a natural source of quantum maggots.

How can spacetime evolve *in* time when it *is* time?

closely enough on the world and our calm, structured reality gives way to chaos and randomness.

Only these conjugate pairs are not in themselves random: They are the pairs of properties that would be impossible for an observer to measure simultaneously. In spite of the way quantum fluctuations are typically described, what sits "out there" in the world is not some preexisting reality wiggling around. Experiment has consistently proven that what sits "out there" isn't sitting at all, but waiting. Unborn. Quantum fluctuations are not existential descriptions but conditional ones—they are not a reflection of what is, but of what could be, should an observer choose to make a particular measurement. It's as if the observer's ability to *measure* determines what *exists*. Ontology recapitulates epistemology. The uncertainty of nature is an uncertainty of observation.

The fundamental inability to assign determinate values to all the features of a physical system means that when an observer does make a measurement, the outcome will be truly random. At the tiny scales where quantum effects reign, the causal chain suffers a fatal kink. Quantum mechanics, said its founding father Niels Bohr, "is irreconcilable with the very idea of causality." Einstein famously balked. "God doesn't play dice," he said, to which Bohr replied, "Einstein, stop telling God what to do."

But perhaps it is we who are to blame for expecting causality to hold up in the first place. Evolution has trained us to find causal patterns at any cost. As our ancestors wandered the African savanna, the ability to suss out effects from their causes marked a line between life and death. *She ate that speckled mushroom and then fell ill. The tiger crouched before it pounced.* Narrative equals survival. Natural selection had no use for quantum physics—how were we to see it coming? Nonetheless, here it is. Causality is an approximation. Our minds, hungry for story, reel.

Is that it, then? The answer to the question of "why being" is simply that there is no "why," that existence is a random quantum fluctuation? Then we can forget explanation altogether and simply quantum leap across James's bridge. *How did something come from nothing? No reason.* Unfortunately, the trick only takes us so far. While cosmologists do believe that the laws of quantum mechanics can spontaneously generate a universe, this story just passes the buck. For where did the laws come from? Remember, we wanted to explain how something came from *nothing*—not how something came from the preexisting laws of physics. Removing causality from the equation is not enough. The paradox stands.

THERE WAS NOTHING. Then, there was something.

The lead character in this story is Time, Bearer of Change. Could the key to solving our paradox be the denial of time itself? If time, as Einstein said, is but a stubbornly persistent illusion, then we can dispense at once, not just with causality issuing from natural laws, but also with the question of where those laws came from. They didn't come from anywhere, because nothing evolves. The narrative dissolves. There is no story. There is no bridge.

The notion of an eternal universe—or a cyclic one, fueled by eternal return—makes appearances in our earliest myths and stories, from Bantu mythology to the Australian Aboriginal "Dreamtime" to Anaximander's cosmology to the Hindu Puranas texts. One can see the appeal. Eternity evades nothingness.

In the modern era, this ancient idea returned as the steady-state theory, formulated by Sir James Jeans in the 1920s and refined and popularized by Fred Hoyle and others in the late 1940s. The universe expands, they said, but new matter is constantly popping into existence to fill in the gaps, so that, on net, the universe never changes at all. That theory turned out to be wrong. It was supplanted by the Big Bang theory and eternity was reduced to a mere 13.8 billion years.

But in the 1960s, the eternal universe reappeared in a strange new form—specifically, in an equation that looked something like this: $H(x)|\Psi\rangle = 0$. The physicists John Archibald Wheeler and Bryce DeWitt wrote the equation—which is now known as the Wheeler-DeWitt equation, though DeWitt prefers to call it "that damned equation" (no relation to that goddamned particle)—in their attempt to apply the strange laws of quantum mechanics to the universe as a whole, as described by Einstein's theory of general relativity. It's the right-hand side of the thing that's worth noting: zero. The total energy of the system is zilch. There is no time evolution. Nothing can happen. The problem, ultimately, is that Einstein's universe is a four-dimensional spacetime, a combination of space and time. Quantum mechanics, meanwhile, requires the wavefunction of a physical system to evolve *in* time. But how can spacetime evolve *in* time when it *is* time? It's an infuriating dilemma—a universe described by quantum mechanics is inevitably frozen. The Wheeler-DeWitt equation is steady-state cosmology inverted. Rather than a universe that always was, we find ourselves with a universe that never will be.

In and of itself, the Wheeler-DeWitt equation elegantly solves our problem. *How did something come from nothing? It didn't.* Of course, it's a perplexing solution given that, well, we're here.

And that's precisely the point. In quantum mechanics, nothing happens until an observer (be it a human or any other configuration of particles) makes a measurement. But when it comes to the universe as a whole, there is no observer. No one can stand outside the universe. The universe *as a whole* is stuck in an eternal instant. But things look different here on the inside.

On the inside, an observer can't measure the whole universe, and by necessity splits reality in two—observer and observed—by the simple yet profound fact that the observer cannot measure himself. As the physicist Raphael Bousso wrote, "Obviously the apparatus must have at least as many degrees of freedom as the system whose quantum state it attempts to establish." The philosopher of science Thomas Breuer used a Gödelian argument to emphasize the same point: "No observer can obtain or store information sufficient to distinguish all states of a system in which he is contained."

As observers, we are forever doomed to see only a piece of the larger puzzle of which we are a part. And that, it turns out, could be our saving grace. When the universe splits in two, the zero on the right-hand side of the equation takes on a new value. Things change. Physics happens. Time begins to flow. You might even say the universe is born.

If that sounds like retrocausation (the future causing events in the past)—well, it is. Quantum theory requires this strange reversal of time's arrow. Wheeler emphasized this fact with his famous delayed choice experiment, which he first posed as a thought experiment but that was later demonstrated successfully in the lab. In the delayed choice, an observer's measurement in the present determines the behavior of a particle in the past—a past that can stretch back for millions of years, or even 13.8 billion. The causal chain turns in on itself, its end links back to its beginning: James's bridge is a loop.

Could it be that something is just what nothing looks like from the inside? If so, our discomfort with nothingness may have been hinting at something profound: It is our human nature that recoils at the notion of nothing, and yet it may also be our limited, human perspective that ultimately solves the paradox.

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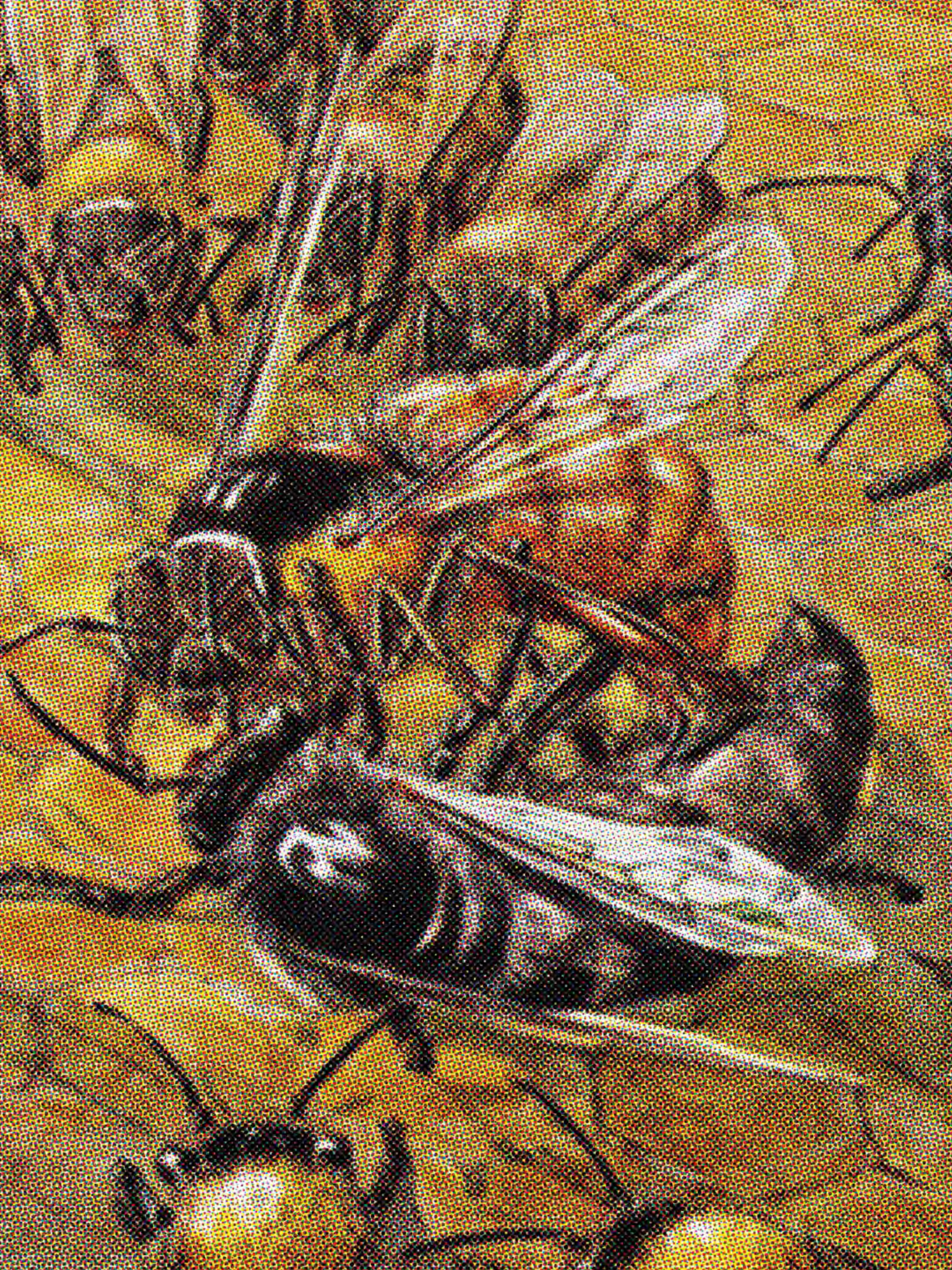

Loyalty Nearly Killed My Beehive

My queen was a dud, and her replacement had been murdered

BY JOHN KNIGHT

S**OME TIME AGO I READ** a short story by Roald Dahl called "Royal Jelly." It's the tale of a father desperately searching for ways to save his malnourished infant daughter who refuses her mother's milk. This man is an apiarist, and while looking for answers, he picks up the latest article on royal jelly—the microbial mix that honeybees feed to their larva when they want to raise a new queen. "Royal jelly ... must be a substance of tremendous nourishing power," he eventually tells his wife when she discovers that he has been secretly feeding it to their child, "for on this diet alone, the honey-bee larva increases in weight 1500 times in five days!" Soon his daughter is rapidly gaining weight and ravenous for her milk.

I became fascinated with bees after reading this story. I bought guidebooks, joined beekeeping meetups, watched documentaries, and, last year, finally sent away for a nuc of 20,000 bees. I asked a friend if she thought this was a good idea, and after a telling pause, she said, "Well, you'll have to be okay with being *that guy*." Undeterred, I installed the bees on the roof of my Brooklyn apartment and began the absurd process of learning how to keep them alive. Incredibly, they flourished, and by October I had perhaps 70,000 bees and had harvested nearly 30 pounds of honey.

Then, this past spring, disaster struck. The queen wasn't laying fertilized eggs, and if I didn't act quickly, the hive would be dead by the end of summer. Thus began a months-long struggle that I only later realized was really about loyalty: mine to the hive, and the hive's to its queen.

FOR THE FIRST FEW MONTHS I had the hive, I checked on it incessantly. I had no idea what I was looking for, but felt like I had to do something—there were thousands of bees on my roof. If I wasn't opening the hive to pull out frames and check for eggs, I was watching the bees come and go. Worker bees can fly up to 15 foraging flights a day, and seeing them return with little balls of pollen on their hind legs gave me a strange sense of accomplishment.

And I really did become *that guy*. I went to a beekeeping class where I met Jessica, another novice beekeeper, and found that just describing how I was lighting my smoker felt good. She knew what it was like. For months, anyone who expressed mild interest in the hive received a personal tour. Even my roommate, who was allergic to bees, found himself standing on the roof bundled in four sweaters and a mosquito net asking when he could go back inside. I had been thinking and reading about bees for so long that I was oblivious to the fact that not everyone shared my enthusiasm. It wasn't until halfway through the summer that I started noticing how my friends remained on the far side of the roof while I, with bee suit and dish gloves, marched around pulling out frames and yammering on about drones and brood and propolis.

Every beehive is unique, so despite classes and guidebooks, the novice beekeeper inevitably engages in a lot of improvisation. If I had to clear a frame, I brushed the bees off with a feather. When I harvested honey, I used spaghetti strainers and cheesecloth. Worried that my whole approach was too haphazard, I asked Todd Hardie, a friend's father who has an apiary that provides honey for his distillery in Vermont, to come see the hive. We went up to my roof one night in the middle of a torrential rainstorm, and, incredibly, he was impressed. As I shined a nearly-useless flashlight, he grasped the bottom board and tipped the hive back for a brief moment.

"How many brood chambers did you say you have?"

"Three."

"And two honey supers?"

"Yes." We were practically yelling at each other over the rain and wind.

"You're fine. This is one of the best hives I've seen

FRANCESCO IZZO

FASCINATION The author inspecting his hive on a Brooklyn rooftop.

all year." I felt my heart thump a little more quickly. "I've never seen a first-year hive do so well."

"How can you tell?"

"By the weight." He said a full hive needs about 60 to 80 pounds of honey to survive the winter. He thought mine probably weighed 100 pounds. It's rare that a beekeeper can harvest anything their first year. "Whatever you're doing," he shouted, "they like it."

Shortly after Todd's visit, my landlord sold our apartment. For weeks I had dreams about beehives wrapped in plastic bags in the backs of taxis. Finally, I decided to move out, but to keep a set of keys, leave the hive where it was, and hope the new landlord wouldn't raise a fuss. I treated for mites (a crucial beekeeping task), made sure food reserves were up, and left the hive to weather the winter.

As far as I can tell, my queen died sometime in the spring. Queens typically live for about four or five years, so this caught me by surprise. A new queen, however, is a regular event in the life of a hive. Beekeepers frequently replace their queens every year or two to introduce genetic variety and ensure that the hive has a strong monarch who can lay enough eggs to keep the population up. Bees can also raise their own queen, and when I did an inspection early that spring, I was pleased to see that mine had taken the initiative. Before she died, my old queen must have laid a few fertilized eggs that worker bees raised as replacements. They would have selected six or seven fertilized (female) eggs and fed them only royal jelly. When the first queen hatched, she would have immediately killed any unhatched competition and ideally flown a few mating flights, storing enough semen in her abdomen to spend the rest of her life laying eggs.

While a newborn queen may seem ruthless, the success of a beehive hinges on allegiance to its queen. Though she can mate with an average of 12 different drones, there is only one queen, which makes for a hive of closely related bees. As a new queen begins to produce her own pheromones, the hive slowly aligns with her as the old bees die and new workers hatch. In a sense, the hive is genetically wired to be loyal to the monarchy. If the hive was to raise multiple queens, or if the workers were to start laying eggs, the interests of the population would slowly fracture.

In a healthy hive, a queen will lay hundreds, sometimes thousands of eggs each day in spring and summer, which she either fertilizes or doesn't. The fertilized eggs, the females, can either grow to be workers or queens. The unfertilized eggs become male drones that do nothing but inseminate the queen—quite literally, flying bags of semen. Drone bees, though crucial for reproduction, don't forage or sting or raise brood—they can't even feed themselves.

A queen that is properly inseminated will lay eggs in a uniform pattern at the center of a frame. In the middle is a large section of worker brood, and along the outside are a few drone cells. Worker cells have flat tops, while the drone cells are slightly raised, like tiny bubbles. But in my frames that spring, I had only scattered drone brood, a sure sign that something was wrong. In a healthy hive, the ratio of workers to drones is about 3-to-1. By late April my ratio was probably closer to 1-to-1, and new drones were hatching every day.

I'M GENERALLY TERRIBLE at admitting when something is wrong, especially when it comes to the bees. I want so desperately for things to go well that I'll ignore all signs of impending disaster. When I saw the irregular brood, I told myself all was well—the queen would fill out the rest of the frame soon. When I saw that all the eggs were drones, I reasoned that the workers would be along shortly. I even proudly showed the hive to my mother when she came for a visit, asserting that since my hive had raised its own queen, there was an excellent chance it would thrive.

In late April I signed up for a "bee tour" around Brooklyn with some fellow urban beekeepers to compare notes and do some "field work." Embarrassingly, I had never seen another hive beside my own. So on a sunny day in May, I rode my bike to a garden deep in Brooklyn. I showed up late and sweaty, and everyone else was already around the hives at the back of the garden. The email had asked us to bring a bee jacket, which

> For weeks I had dreams about beehives wrapped in plastic bags in the backs of taxis.

I had forgotten, and the only one left was a child's size. With the sleeves just covering my elbows and the hood unzipped, I bashfully edged up to the group gathered around the veteran beekeeper who had come from upstate to show us city-slickers a thing or two.

It was immediately obvious how poorly my hive was doing. Almost every frame in the perfect hive in front of me was already packed with uniform worker brood and even had a little honey in the corners. The bees were industriously packing in pollen and capping cells, and there was the queen scurrying around keeping things in line.

What had happened to my queen? Perhaps there were no drones in the hive to inseminate her when she hatched—they are killed off in the fall because they become just another mandible to feed in the winter. Some of the first eggs a queen lays in the spring are usually replacement drones, but maybe my hive was still drone-less when the new queen emerged. Or maybe it was too cold for her to take a mating flight. Or maybe the chemicals I used to treat for mites compromised the virility of the drones' semen. Whatever the cause, seeing this new hive made the effect obvious.

When our host tried to slip inside for a glass of water, I rushed up to him in my absurd children's jacket, caught him by the shirtsleeve and explained my situation. His face darkened.

"There's not much you can do, really. Try to get a new queen, but this time of year, most breeders don't have any left."

"What will happen if I do nothing?"

"Well, the queen will keep laying drones and soon the workers will all die, and then the drones. If I were you, I'd cut my losses and start again next year."

Someone else volleyed for his attention, asking whether it was important to use organic sugar for feeding. I extricated myself, and felt the panic set in.

Frantically, I spent the rest of the afternoon calling every queen breeder I could find on the East Coast. I eventually found a man in Florida who could send me a queen that would arrive within days. She would cost $50 with shipping. She'd come by regular mail in a small cage about the size of a granola bar with a candied plug, inside a perforated envelope marked "LIVE BEES." After you remove the old queen, he said, you place the new one—cage and all—between the hive's frames, and let her chew her way out through the plug. She'll be laying eggs in a few days.

HOW SWEET IT IS The capped honey cells stored in this frame can supply the bees with enough food through the winter.

FRANCESCO IZZO

BEES HAVE ABOUT 165 pheromone receptors on their antennae and though it's not entirely clear how workers "decide" what to do and when (the question of agency is still very much up for debate), it is certain that the queen's pheromones prompt them to go about their business. When the reigning monarch dies or stops laying eggs in her old age, the change in her pheromones prompts the hive to raise a replacement, as my hive had done. Similarly, if a new queen arrives and releases her pheromones before those of the old queen have dispersed, the hive will consider the new queen an invader, and kill her. Above all, they are loyal to their queen. I did not fully grasp this fact. Because I waited only six hours between queens, the worker bees probably stung my new queen to death within an hour.

A week later, when I realized my new queen was dead, I called Todd with a sinking heart. "The hive is moving in its own direction now," he said, "and it's a different direction than the one you want." In other words, if I did nothing, my honey-producing hive of workers would slowly become an unproductive hive of drones that would all eventually die. My tinkering had seemingly led the bees to cultivating the hive's demise. But at least in this, I was not alone.

If you've heard anything about bees in the past decade, it's that they are dying. Their disappearance is a serious problem, as domesticated honeybees are responsible for pollinating approximately 80 percent of all fruit, vegetable, and seed crops in the United States. There is still much debate among experts about whether so-called Colony Collapse Disorder is a single problem, or whether it might actually be a convenient catch-all that describes multiple threats to beehives. Pesticides, stress, poor diet, infestation, disease, and mismanagement are all possible culprits. In fact, it may not be ideal for hives to be domesticated in the first place. There are feral bee colonies throughout the country that survive perfectly well on their own, even though many began as domesticated hives, like mine. The root of this difference isn't entirely understood, but it appears that feral bees are more genetically diverse than their domestic counterparts. In a kind of DNA re-wilding, feral bees develop a greater range of ways to respond to environmental changes. If DNA is a manual and the environment determines which instructions should be used to accommodate a given situation, feral bees simply have more instruction sets to choose from.

My unraveling colony made clear to me the complex, fraught relationship between honeybee and beekeeper. Bees are tremendously self-sufficient, and follow a set of old and finely tuned instincts. The beekeeper, ideally, needs only to nudge them in the right direction to make them do what he wants: pollinate an almond orchard, or survive on a Brooklyn rooftop. But to do this correctly, the beekeeper needs to understand what it is the hive wants. In my case, Todd was telling me, it wanted to die. Its queen gone, and its new queen rejected, my best efforts were being brushed off. In a bizarre mash of genetics, instinct, and husbandry, the hive and I were now at odds.

NEAR THE END OF the Roald Dahl story, the child's mother begins to worry about all the weight her daughter has gained. She is unnerved by her husband's brash use of the royal jelly and even detects "a touch of the bee about this man." Finally, she undresses the child to weigh her, and sees that though her abdomen has fattened, her arms don't seem to have grown proportionally. "The baby was lying naked on the table, fat and white and comatose," Dahl writes, "like some gigantic grub that was approaching the end of its larval life and would soon emerge into the world complete with mandibles and wings."

The father, on the other hand, is ecstatic. He admits that this isn't even the first time he's put royal jelly to good use—he's been secretly eating it himself for the past year. "Why don't you cover it up, Mabel?" he says to his wife. "We don't want our little queen to catch a cold."

As much as I don't like to admit it, I admire this man. He was determined to fatten up his daughter, and I was determined to save my hive. For better or worse I couldn't stop tinkering. The hive was headed toward disaster, but I refused to follow.

I called my man in Florida again. I alerted the receptionist at work. This time, when the new queen arrived, rather than placing her cage in the center of the hive with all the other bees, I separated the hive in two with a piece of paper. The bees would eventually chew through and reunite the two sides, but cutting the hive in half might mitigate their aggression. I gave them some food and fresh water, and left the hive alone for two weeks. I figured the queen had a 10 percent chance of making it.

So much remains unknown about bees that most of the time beekeeping feels like a matter of luck. As of this writing, my luck is holding. The hive is raising worker brood with a healthy queen. The drone population has leveled out, and there are two brood chambers flush with capped worker cells. There aren't as many bees as last year, but two honey supers are nearly full. I don't know if it will be enough to last the winter, but the new queen seems to be on board with my vision. I don't see her every time I do an inspection, but frequently I'll seek her out, just to make sure. She is, after all, my partner-in-crime, my hive's savior—my little queen.

JOHN KNIGHT is a writer, editor, and beekeeper whose writing has appeared in *The New York Times*, *New York Magazine*, *The Millions*, and elsewhere.

“ANGST AND THE EMPTY SET”

ILLUSTRATION BY **LINDA ZACHS**

Why We Can't Rule Out Bigfoot

How the null hypothesis keeps the hairy hominid alive

BY CARL ZIMMER

ILLUSTRATION BY JEFFREY ALAN LOVE

I **RECENTLY GOT AN EMAIL** from an anthropologist commenting on a new report in the *Proceedings of the Royal Society*. The topic of that report was Bigfoot—or rather, a genetic analysis of hairs that people over the years have claimed belong to a giant, hairy, unidentified primate.

The international collaboration of scientists, led by University of Oxford geneticist Bryan Sykes, found no evidence that the DNA from the hairs belonged to a mysterious primate. Instead, for the most part, it belonged to decidedly unmysterious mammals such as porcupines, raccoons, and cows.

My correspondent summed up his opinion succinctly: "Well, duh."

This new paper will not go down in history as one of the great scientific studies of all time. It doesn't change the way we think about the natural world, or about ourselves. But it does illustrate the counterintuitive way that modern science works.

People often think that the job of scientists is to prove a hypothesis is true—the existence of electrons, for example, or the ability of a drug to cure cancer. But very often, scientists do the reverse: They set out to disprove a hypothesis.

It took many decades for scientists to develop this method, but one afternoon in the early 1920s looms large in its history. At an agricultural research station in England, three scientists took a break for tea. A statistician named Ronald Fisher poured a cup and offered it to his colleague, Muriel Bristol.

Bristol declined it. She much preferred the taste of a cup into which the milk had been poured first.

"Nonsense," Fisher reportedly said. "Surely it makes no difference."

But Bristol was adamant. She maintained that she could tell the difference.

The third scientist in the conversation, William Roach, suggested that they run an experiment. (This may have actually been a moment of scientific flirtation: Roach and Bristol married in 1923.) But how to test Bristol's claim? The simplest thing that Fisher and Roach could have done was pour a cup of tea out of her sight, hand it to her to sip, and then let her guess how it was prepared.

If Bristol got the answer right, however, that would not necessarily be proof that she had an eerie perception of tea. With a 50 percent chance of being right, she might easily answer correctly by chance alone.

Several years later, in his 1935 book *The Design of Experiments*, Fisher described how to test such a claim. Instead of trying to prove that Bristol could tell the difference between the cups of tea, he would try to reject the hypothesis that her choices were random. "We may speak of this hypothesis as the 'null hypothesis,'" Fisher wrote. "The null hypothesis is never proved or established, but is possibly disproved, in the course of experimentation. Every experiment may be said to exist only in order to give the facts a chance of disproving the null hypothesis."

Fisher sketched out a way to reject the null hypothesis—that Bristol's choices were random. He would prepare eight cups, putting milk first into four of them, and milk second into the other four. He would scramble the cups into a random order and offer them to Bristol to sip, one at a time. She would then divide them into two groups—the cups that she believed had received milk first would go in one group, milk second in the other.

Sightings And Such

Throughout the years, dubious "proof" has been presented for the existence of Bigfoot, the Abominable Snowman, yetis, and countless other mysterious creatures. None have been proven to exist, but none have been proven not to exist, either.

1954
This photograph shows the scalp of a yeti—if you believe the *Daily Mail*. They sent a group of scientists into the Himalayas in search of these creatures.

1967
A video allegedly shows Bigfoot talking a walk in the woods. Only problem: One of the amateur filmmakers' friends later claimed the video was of him in a gorilla suit.

2007
The photographer of this image, taken in Pennsylvania, claims it shows a young Sasquatch. A local wildlife official said it's more likely a bear with severe mange, but neither story could be conclusively proven or disproven.

WIKIPEDIA

Bristol reportedly passed the test with flying colors, correctly identifying all eight cups. Thanks to the design of Fisher's experiment, the odds that she would divide eight cups into two groups correctly by chance were small. There were 70 different possible ways to divide eight cups into two groups of four, which meant that Bristol could identify the cups correctly by chance only once out of every 70 trials.

Fisher's test couldn't completely eliminate the possibility that Bristol was guessing. It just meant that the chance she was guessing was low. He could have reduced the odds further by having Bristol drink more tea, but he could never reduce the chances she was guessing to zero.

Since absolute proof was impossible, Fisher preferred to be practical when he ran experiments. At the lab where he and Bristol worked, Fisher was charged with analyzing decades of collected data to determine whether that information could divine details, like the best recipe for crop fertilizer. Scientists could use that data to design ever larger experiments with increasingly more accurate results. Fisher thought it would be pointless to design an experiment that needed centuries to yield results. At some point, Fisher believed, scientists had to just call it a day.

He believed that a sensible threshold was 5 percent. If we assumed that the null hypothesis was true and found that the odds of observing the data were less than 5 percent, then we could safely reject it. In Bristol's case, the odds were comfortably below Fisher's threshold, at just 1.4 percent.

Thanks in large part to Fisher, the null hypothesis has become an important tool for scientific discovery. You can find tests of null hypotheses in every branch

> "Every experiment may be said to exist only in order to give the facts a chance of disproving the null hypothesis."

of science, from psychology to virology to cosmology. And scientists have followed Fisher in using a 5-percent threshold.

Which brings us back to Bigfoot.

People have been claiming they've seen hairy humanoids for decades. They've offered up grainy photos, ambiguous casts of footprints, and enigmatic clumps of hair. In recent years, they've even tried to extract DNA from hair, but scientists have dismissed these genetic studies because they didn't involve standard safeguards routinely used in such research.

Bigfoot advocates have repeatedly claimed that professional scientists are willfully ignoring compelling evidence. The problem, in fact, is that the advocates haven't been approaching the question of Bigfoot in a scientific fashion. So two years ago Sykes and his colleagues decided to run a scientific study of those hairs from an "anomalous primate." And that involved creating a null hypothesis to try to reject.

The null hypothesis they developed was this: The hairs purported to come from Bigfoot (or the Abominable Snowman or other regional varieties of the creature) belonged not to a previously unknown primate, but to known mammals. They extracted DNA fragments from 30 different hair samples and were able to isolate the same short stretch of DNA from each. They then compared that stretch to the corresponding stretch of DNA sequenced from many living mammals.

The results were clear: The scientists found precise matches for all 30 samples in previously known mammals.

Does this mean Sykes and his colleagues have proved that Bigfoot does not exist? No. It simply means that Sykes, unlike Fisher with his tea test, could not reject the null hypothesis. The question remains open, and—if Bigfoot doesn't exist—always will.

That's not to say Sykes' study didn't offer its own surprises. Two hair samples from the Himalayas matched a DNA sequence that was extracted from a 40,000-year-old fossil of a polar bear. Stranger still, their DNA was not a match to living polar bears.

In their report, Sykes and his colleagues offer a scenario for how such a result could have come about. It's possible that ancient polar bears and brown bears interbred, and some living bears in the Himalayas still carry a bit of that ancient polar bear DNA.

Some skeptics have offered up an alternative explanation for Sykes' finding. It's possible that the polar bear-like DNA actually comes from a living mammal—perhaps a brown bear—that happened to pick up a few mutations that created a false resemblance to that ancient polar bear DNA.

What these skeptics have done, in effect, is create a null hypothesis. And there's a straightforward way to set about disproving it. Scientists would need to find more DNA from these mysterious bears. If other regions of the DNA also matched ancient polar bears, then scientists could reject the null hypothesis.

And so science carries on, from one null hypothesis to another.

CARL ZIMMER is a columnist for *The New York Times* and the author of 12 books, including *A Planet of Viruses*.

"THE FIRST DAY"
ILLUSTRATION BY **DADU SHIN**

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ARISTOTLE'S METAPHYSICS WAS BASED on eternal forms, and some 2,000 years later, Newton's apple had not fallen far from the tree: He believed his equations described an eternal universe, reflecting the mind of God.

It would be centuries more before these eternities began to fragment. In the 1840s biologists realized that most of the diversity of life we see on Earth today appeared "abruptly" in a 20-million-year period. In 1931 Georges Lemaître proposed that our universe had "hatched" from what he called a "cosmic egg." Even the workings of science itself gained a revolutionary flavor, with the work of Thomas Kuhn in 1962. Today, ideas like chaos theory, critical points, and punctuated equilibria provide a firm foundation for understanding sharp left turns and sudden appearances.

But there is more to this story than the progress of science. The question itself—"how did things begin?"—seems to carry an inescapable abruptness. After all, what can we say came before the beginning? In answering this broader question, we have been imagining "Big Bangs" for a long time indeed.

Welcome to "Big Bangs."

—MS

"What if we discovered that we are surrounded by chemically incompatible aliens, and learned that all that we thought was inevitable and optimal about our biology and evolution is merely a fluke?"

CALEB SCHARF

"Can You Ever Really Know an Extraterrestrial?" p. 92

Big Bangs

SUDDENLY, A NEW WORLD

Can You Ever Really Know an Extraterrestrial?

Knowledge about aliens might be as dangerous as the aliens themselves

BY CALEB SCHARF

ILLUSTRATION BY RACHELL SUMPTER

IMAGINE THAT YOU'VE LIVED your entire life in a small village deep within a continental wilderness. For centuries this community has been isolated from the rest of the world. One day you go out exploring, skirting the edges of known territory. Suddenly, and against all expectations, you stumble across a signpost embedded in the ground. The script is highly unusual, foreign, but the text is clear enough. It says, simply, "We Are Here."

The question is: What happens next?

There might be happiness and celebration to mark the end of isolation, or the news might be met with a shrug. But human nature suggests it's more probable that this discovery triggers a chain of events that lead to utter disaster.

Suddenly your safe haven is threatened by an unknown "them." Your time-tested principles of governance and social order are put under pressure. Gossip, rumor, and conjecture will gnaw away at your stable home. Barricades and armed forces will be raised at enormous cost, crops and repairs will be forgotten. A community will lurch toward its own collapse. Yet there is little more than a half-realized idea represented by this impersonal signpost, a whispered implication that infects the world with its ambiguity.

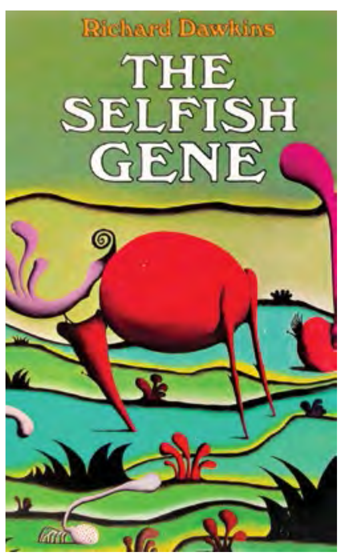
This tale is not the opening sequence of a B-grade movie, but an allegorical version of what might, just possibly, happen after we solve one of the oldest scientific and philosophical puzzles—whether or not we have neighbors "out there" in the wilderness of the cosmos.

TODAY, THE PROSPECTS FOR finding evidence of life beyond the Earth fall into three well-known categories. First is our exploration of the solar system. Mars is arguably the prime target because it offers a planetary template that, while alien, best parallels certain terrestrial environments—and it is directly accessible. At this very moment we have robotic wheels on Martian regolith and sharp eyes in orbit. More Mars missions are lining up: NASA's MAVEN entered orbit in late September 2014, as did India's Mangalyaan craft. And plans are afoot for the InSight seismological probe, Europe's ExoMars, a Mars 2020 rover, a sample return, as well as the ever-present speculations for sending a human contingent.

But Mars is not the only fruit. The icy moons Enceladus and Europa both exhibit hallmarks of subsurface liquid water. In the case of Europa, a dark ocean with twice the volume of all Earth's surface oceans conceivably exists in contact with a rocky core—with potential for a deep hydrothermal oasis. Recently discovered geyser-like eruptions into space from both offer hope of a sampling mission to look for signs of life.

In the second category, vastly farther beyond, lie the exoplanets. We now know this population to be enormous—tens of billions of terrestrial-scaled planets ranging from geophysical youth to old age. Some of these worlds could be passable Earth-analogs. The chase is on to measure the atmospheric chemical composition of at least a few of the nearest such worlds, looking for the fingerprints of a biosphere. NASA's 2018 James Webb Space Telescope and the next-generation of 30-meter diameter Earth-bound astronomical observatories possess the capabilities to make crude measurements of such components.

Third, there is the ongoing search



GENES TO MEMES Richard Dawkins' 1976 book defined a meme as an idea that spreads within a culture. What if a meme came from very, very far away?

Shooting memes back and forth across the void is asking for trouble.

for extraterrestrial intelligence, or SETI. Scouring the celestial radio and optical spectrum for structured, artificial signals—this is the highest-risk, highest-reward effort of all. Success would not only mean that life exists somewhere else, but that there is recognizable technological intelligence other than ours in the universe.

But the knowledge being sought from all these efforts could change far more than just our scientific understanding. Like a sign in the wilderness, the potential exists for new information to infect our collective consciousness before we've realized what's happening. It is capable of seeding our minds with ideas that take on their own form of life as competitive agents that question the status quo, seeping into our thoughts and behaviors. In fact we already have a label for these types of self-propagating, evolving packets of information—we call them memes.

In 1976, writing in his book *The Selfish Gene*, evolutionary biologist Richard Dawkins proposed the term meme to describe something that spreads within a culture; whether it's a catchy phrase, chairs with four legs, a style of clothing, or an entire belief system. In this sense a meme is a mutating, replicating piece of human cultural evolution—a viral entity.

As an information-obsessed, intensely social species, we're particularly vulnerable to memes. And not all memes are innocuous—some become toxic when they meet other established memes. Witness the clash between Western mores and conservative Islam.

What if we discovered that we are surrounded by chemically incompatible aliens, and learned that all that we thought was inevitable and optimal about our biology and evolution is merely a fluke? Such a discovery runs counter to our Copernican ideals and upends any tidy rationalization of the deep connections between life and the fundamental constituents of the cosmos.

Or what if we detected an extraterrestrial signal along the lines of "You Are All Going To Die?" Even if this was a translation error, or a misinterpretation of an alien effort at existential camaraderie, our species could be quickly sent into a tailspin, potentially wrecking our civilization as effectively as any physical weapon.

A message with a more straightforward intent could have equally ruinous effects. It could be a new scientific insight or technological blueprint sent as an item of interstellar trade or détente, but have a destabilizing effect on Earth's economy. Or a message could contain

ANYONE THERE? The 27 radio antennas of the Very Large Array in New Mexico have been used to listen to the heavens for signs of intelligent life. Data from facilities like this one could be filtered through a planetary firewall.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They Walk Among Us

What if aliens are already here on Earth? The idea has drawn movie-goers into theaters for years for its suspense and humor—but also because of what it suggests about our place in the universe.

1976
The Man Who Fell To Earth— An alien comes to Earth looking for water, and finding love.

1984
The Brother from Another Planet— A crash-landing on Earth leads an alien to settle in Harlem.

1984
Starman—Another crash landing, this time in Wisconsin. Again with the love.

a philosophical statement interpreted to have religious meaning, triggering conflict and disorder. Even "Is Anyone Out There?" would be problematic—the decision to answer or not could provoke more than just verbal conflict within our species.

We may also agree to reach out, to our own detriment. If we identify the chemical signatures of a biosphere on a nearby exoplanet there will be temptation to send a focused message—a long-shot effort at communication. In our impatience we have already made such attempts. In 1974, for example, the Arecibo radio observatory beamed a meme-laden message of 1,679 binary digits towards a distant globular star cluster. Its contents included a simple string of numbers, a basic blueprint describing DNA, a cartoon human figure, and the layout of our solar system. We've also spent decades blaring out our wideband analog radio and TV transmissions before downsizing to digital. With a real target we might even consider sending a probe, especially if we ever develop the means to traverse interstellar space at a substantial fraction of the speed of light.

But these behaviors are terribly dangerous for us if they prompt a response from our cosmic neighbors, as well as for any intelligent natives of these other worlds. Shooting memes back and forth across the void is asking for trouble.

WHAT ARE WE TO DO? We still want to know whether we're alone or not. Scientific curiosity and logic surely demands this for any rational entity. It's a central piece of the puzzle for trying to understand our own origins and nature, our place in the universe.

The answer may lie in building a planetary firewall, a kind of "meme armor" to shield us from damaging knowledge of extraterrestrial life, while still allowing us to learn about the cosmos. It would be an artificial and autonomous construct that would take over the job of SETI, and even the task of exoplanet-hunting astronomers. By providing an algorithmic or physical barrier to the rest of the universe, it would help sift and control the flow of information—rather like an Internet firewall that defends against viruses by scrutinizing the origin and intent of packets of data.

The armor might involve a unilateral ban of private telescopes or radio antenna with enough sensitivity to chance upon extraterrestrial signposts. It could be equipped with its own automated listening posts and telescopes—spoon-feeding sanitized results to its masters. Careful (and hopefully unhackable) firewall programming would sift and sanitize its sightings. The riskiest data could be stored in case of true existential disaster—when an extraterrestrial meme can do no worse damage than is already in progress—a library of last resort for a species, the ultimate example of "In Case of Fire, Break Glass."

Such armor could also present a camouflaged state to onlookers; blocking attempts to discern the presence or nature of life on Earth, much like the hidden host addresses used behind today's computer firewalls. Or—in a far more sinister version—it could seek to actively infect other worlds with destructive memes in order to reduce potential threats to Earth.

Just as our highest security computer systems are physically isolated from the net, a more ambitious hardware-based armor could veil the Earth's view of the universe. A giant high-tech Faraday cage made with pixel-like optical elements to control precisely what electromagnetic radiation gets through—an informational version of the air-filtration and containment of a biohazard lab. More drastic still would be to abandon our meme-vulnerable planet altogether. We'd build a vast Dyson sphere—that staple of futurology and sci-fi—and live on the inside facing our star, sealed away from the infectious cosmos.

These are obviously hugely speculative, if not fanciful, ideas. Perhaps our form of intelligence actually has a degree of natural immunity to extraterrestrial meme infection. After all, since grasping the concept that we inhabit one microscopic piece of an immense universe with no physical center, our species has not actually self-destructed—at least not yet. Most importantly, I don't think we should be dissuaded from seeking out the most fecund places in the cosmos, and we're unlikely to want to ever shield ourselves from the glory of the celestial skies.

But, as the adage goes, we should be careful what we wish for.

CALEB SCHARF is an astrophysicist and the Director of Astrobiology at Columbia University in New York. His latest book is *The Copernicus Complex: Our Cosmic Significance in a Universe of Planets and Probabilities.*

To Understand Religion, Think Football

Sacred beliefs likely arose out of prehistoric bonding and rituals

BY STEVE PAULSON

THE INVENTION OF RELIGION is a big bang in human history. Gods and spirits helped explain the unexplainable, and religious belief gave meaning and purpose to people struggling to survive. But what if everything we thought we knew about religion was wrong? What if belief in the supernatural is window dressing on what really matters—elaborate rituals that foster group cohesion, creating personal bonds that people are willing to die for?

Anthropologist Harvey Whitehouse thinks too much talk about religion is based on loose conjecture and simplistic explanations. Whitehouse directs the Institute of Cognitive and Evolutionary Anthropology at Oxford University. For years he's been collaborating with scholars around the world to build a massive body of data that grounds the study of religion in science. Whitehouse draws on an array of disciplines—archeology, ethnography, history, evolutionary psychology, cognitive science—to construct a profile of religious practices. Whitehouse's fascination with religion goes back to his own groundbreaking field study of traditional beliefs in Papua New Guinea in the 1980s. He developed a theory of religion based on the power of rituals to create social bonds and group identity. He saw that difficult rituals, like traumatic initiation rites, were often unforgettable and had the effect of fusing an individual's identity with the group. Over the years Whitehouse's theory of religiosity has sparked considerable debate and spawned several international conferences.

Whitehouse remains a busy man in charge of various research projects. I caught up with him during a brief layover in London between trips to South America and Hong Kong. He'd just returned from Brazil, where

ILLUSTRATION BY MÉLANIE DEYME

There's a sacredness to religion that people don't associate with supporting a football team. But frankly, a lot of football fans hold their team pretty sacred.

he met with two research groups studying how soccer fans bond with each other in that football-mad nation. Our interview covered a wide range of topics: the social utility of difficult, often painful rituals; the psychological power of "God" in large societies; and why it's so hard to come up with a good definition of religion.

How far back can we trace religion in human history?

Well, one thing we need to sort out is what we mean by "religion." People use this as a blanket term for many different things—belief in God or gods, belief in souls and the afterlife, magical spells, rituals, altered states of consciousness. Some of these things are incredibly hard to see in the ancient past, particularly in prehistory.

So what do you look for?

Archaeologists spend a lot of time looking for evidence of ritual activity. Some of the best evidence of belief in the afterlife comes from grave goods like pendants and beaded necklaces. Some African burial sites date back more than a quarter of a million years.

How do you know these burial sites had something to do with the afterlife?

When people leave grave goods, there's a strong suggestion they imagine that's not the end of the person they're laying to rest. Some of the paleolithic cave paintings are also suggestive. Lots of materials in those caves suggest that altered states of consciousness were being experienced. These environments have remarkable acoustics, and you can imagine how lighting could be manipulated to enhance the effects on people.

What are you learning about the origins of religion based on this ancient archeological evidence?

When we can see how frequently certain rituals were performed, we think it's possible to estimate—based on animal remains, for example—how often feasting events occurred. Some rituals involved killing large and dangerous animals. It's been estimated that meat from a wild bull could feed 1,000 people. We can learn from burials, particularly in houses where burials are associated with founding events or closures. We can then estimate the frequency of particular rituals. The frequency of a ritual will be inversely proportional to the level of arousal it induces. Those inducers include sensory pageantry, singing, dancing, music, altered states of consciousness, and painful or traumatic procedures. Religions with high-frequency rituals will be more hierarchical than traditions that lack those rituals.

One common explanation for the origin of religion is that gods and supernatural beings could explain things that didn't make any sense, whether it was the explosion of thunder or the death of a child. Was that the root of religious belief?

I suppose people do try to fill in the gaps in their knowledge by invoking supernatural explanations. But many other situations prompt supernatural explanations. Perhaps the most common one is thinking there's a ritual that can help us when we're doing something with a high risk of failure. Lots of people go to football matches wearing their lucky pants or lucky shirt. And you get players doing all sorts of rituals when there's a high-risk situation like taking a penalty kick.

So ritualistic activities in a football match are not that different from explicitly religious rituals?

No. In fact, I find it odd that people would even want to think that they're different. Psychologically, they're so incredibly similar.

GO LONG FOR GOD Rituals calling for supernatural intervention arise from the same psychological impulse in religious followers and sports fans, argues anthropologist Harvey Whitehouse.

JOE JOHNSON

But presumably what sets religion apart is something to do with the transcendent, with another dimension of reality.

It's true that there's a certain sacredness to religion that people don't associate with supporting a football team. But frankly, a lot of football fans hold their team and all its emblems pretty sacred. We tend to take a few bits and pieces of the most familiar religions and see them as emblematic of what's ancient and pan-human. But those things that are ancient and pan-human are actually ubiquitous and not really part of world religions.

Again, it really depends on what we mean by "religion." I think the best way to answer that question is to try and figure out which cognitive capacities came first. We know that tool-use goes back deep in history. *Homo habilis*, otherwise known as handy man, is an early species that used tools, so it's quite possible that he had some notion of creator beings. Language clearly plays an important role in some aspects of religion, like the development of a doctrinal system. But I'm not sure it's necessary for many of the fundamental beliefs that undergird what we think of as religion.

All religions seem to have creation stories. Don't you need language to formulate this kind of mythic imagination?

When you look at the myths of many cultural traditions, they seem to have a kind of dreamlike quality. Often they're inspired by dreams. Dreaming seems to be a widespread feature of the mammalian brain, so while sharing dreams depends on language, having dreams doesn't require language. I'm guessing the mythic imagination wouldn't depend on having a language.

At some point in human history many societies switched from animistic forms of religion to institutionalized systems that are closer to today's religions. How do you explain this transition?

The really critical transition is one that occurs in the gradual switch from a foraging, hunting-and-gathering lifestyle to settled agriculture, where you're domesticating animals and cultivating crops. What happens is a major change in group size and structure. I think religion is really a core feature in that change. What we see in the archeological record is increasing frequency of collective rituals. This changes things psychologically and leads to more doctrinal kinds of religious systems, which are more recognizable when we look at world religions today.

Why did that transformation occur in agricultural societies?

The cooperation required in large settled communities is different from what you need in a small group based on face-to-face ties between people. When you're facing high-risk encounters with other groups or dangerous animals, what you want in a small group is people so strongly bonded that they stick together. The rituals that seem best-designed to do that are emotionally intense but not performed all that frequently. But when the group is too large for you to know everyone personally, you need to bind people together through group categories, like an ethnic group or a religious organization. The high frequency rituals in larger religions make you lose sight of your personal self.

I suppose an example of social bonding would be the Muslim practice of praying five times a day.

Or in Christianity, it's going to church regularly to attend services. All large-scale religions have rituals that people perform daily or at least once a week. We think this is one of the key differences between simply identifying with a group and being fused with a group. When you're fused with a group, a person's social identity taps into personal identity as well. And identity fusion has a number of behavioral outcomes. Perhaps most importantly, fused individuals demonstrate a significant willingness to sacrifice themselves for their groups.

What about bonding in smaller groups?

A lot of small groups are bound together through painful or frightening initiation rituals, particularly in groups that face high levels of threat from people outside their group. You need to stand together firmly to resist. Where I worked in New Guinea, a lot of the small tribal groups had initiation rites for boys and young men. They emerged as tightly bonded military units capable of carrying out raids against neighboring villages. We see the same sort of thing in modern armies. The elite forces have dysphoric training programs and informal initiation rites that bind the group together.

A secular example of these initiations would be the hazing rituals in a college fraternity.

That's right. We're developing a survey to see whether the intensity of hazing rituals in fraternities and sororities correlates with group fusion. We've also been researching military groups and football fans. What we're finding is that football fans that suffer more are also more bonded. Going through bad experiences together is actually a more powerful bonding agent than simply having a good time.

Doesn't a well-trained army have to break down a soldier's individuality so that he's committed to helping his comrades?

I think that's right. Painful or bad experiences are remembered better and become part of our sense of who we are. Sharing those powerful experiences breaks down the boundary between self and other and creates the psychological state that we call fusion. One of the interesting correlates of being fused with a group is willingness to fight and die for it. So people willing to make huge sacrifices to groups are typically fused with them.

What brought you to Papua New Guinea?

I didn't intend to study religion. I'd gone out there to study economic anthropology, but these people had other ideas. They were all members of a religious movement calling itself the Kivung, which had a huge number of beliefs and practices geared toward bringing the ancestors back from the dead. This was what people really wanted me to understand.

Can you describe some of these rituals to bring back the dead?

There were two aspects to the movement and this is what has driven so much of my later research. There was a large tradition uniting hundreds of villages and thousands of followers across quite a wide region. It involved very high frequency rituals, most of which were focused on laying out offerings to the ancestors in specially constructed temples. Operating on a very large scale, it was quite hierarchical and very well organized. But there were also small groups that sporadically broke away and performed much more emotionally intense rituals that seemed to have a very powerful bonding effect, even though they never succeeded in bringing the ancestors back from the dead.

What were these intense rituals in smaller groups?

In the village where I lived, they performed special rituals where they discarded their clothes and went around naked, which had quite an emotional impact, particularly on women who were exposing their bodies to the predatory gaze of men. They destroyed all their animals and had huge feasts, performing a mass marriage and lots of rituals that were intended to herald the return of the ancestors. They performed vigils under quite difficult conditions where people were forbidden to leave and were forced to endure unpleasant conditions.

Did they ever explain why they thought these rituals would bring back their ancestors?

They had a complex doctrinal system that explained the history of the world and the relationships between their groups and white folks. It's a long and complicated story. As in any religion, I'm not sure that everyone bought into every detail of the doctrine. The most compelling aspect of this belief system is that they would be released from a history of exploitation through a brotherhood with invading colonial powers.

They talked about a period when ethnically European businessmen and technologists would appear in the jungle and create, magically overnight, huge high-rise buildings and cities, and they would have a Western

PREHISTORIC RITES Harvey Whitehouse points out bull horns at Çatalhöyük, an archaeological excavation in Turkey. Through an analysis of artifacts at the settlement, which thrived around 7000 B.C., Whitehouse has discerned "high-arousal" rituals associated with a religious life.

lifestyle as a result. But those European people would actually be ancestors of the group who'd just come back from the dead but with the appearance of white skin and European-type hair.

So they thought bringing back their ancestors would give them an opulent lifestyle?

I don't think it was just about being wealthy in a crass materialistic sense. It was about release from all the sufferings of the hard life that they lived in the forest, where horrible sores, tropical ulcers, malaria, and all kinds of diseases and injuries—including premature death of loved ones—are a common part of everyday life. They were dreaming of a time when all of that suffering would be eliminated.

You're suggesting you don't have to reduce religious experience to belief systems. It's the experience itself that sweeps you along and binds you to other people.

It's about both belief and experience. I do think we can separate the two. Imagine having a brain that's naturally predisposed to believe some things more readily than others, and then over generations, cultural systems develop in ways that essentially play into those predispositions. The point is that our experiences are made meaningful by our implicit beliefs and the two basically work together.

JUSTIN BARRETT

People can train themselves to dismiss religious intuitions, but I don't think they can eradicate them.

If there's such a thing as a "big bang" of religion, it would seem to be the Axial Age, the period from 800 to 200 B.C. when various sages—Plato, Confucius, Jeremiah, the Buddha—all emerged. These people not only shaped some of today's major religions, they helped create the world we still live in. Do you see this as a watershed in the history of religion?

I think there were some major social and cultural changes during that period, but were they distinctive enough to think of that age as axial or pivotal? It's hard to answer that without looking like we're cherry-picking the evidence to fit the argument that we prefer. To adjudicate on this question we need a large database in archeological, ethnographic, and historical materials—a huge storehouse of information where we can look for correlations over long time periods going back as far as history will allow.

Do you think science can fully explain religion?

I don't know about fully explain. I'd like to think that science will one day be able to explain why we're inclined to adopt these different things that we lump together as religion, but I don't think explaining religion is the same as explaining it away. I don't think science will ever be able to tell us whether or not there's a god. That will always be a matter of faith. I'm in favor of a humble approach, but I do think that humility should cut both ways. Religious people should be open to the possibility that some of the things they find most mysterious about the meaning of life or the cosmos might actually turn out to be explainable. Of course, science has been pretty successful at turning certain mysteries into soluble problems. But at the same time I think much of human life takes us beyond the scope of scientific explanation and that's true of religion, too.

Psychologically, why is God such a powerful idea?

It may be a product of cultural evolution and the shift to much larger and more complex societies. When you use the singular "God," you're talking about some kind of high god, which probably means a god that's omniscient and cares about the morality of our behavior and punishes us when we behave badly. That's a relatively recent cultural innovation that may have been an adaptation to living in very large societies.

So once society becomes very big, you can no longer see what everyone is doing and you can't police moral behavior. But if this high god is watching you, there's still an imperative to be good?

It's become known as the "supernatural watcher" hypothesis. The idea of an eye in the sky is quite compelling. But I think we need more empirical research to be really confident that it's true.

I'm curious, are you religious yourself?

Well, I've got the full repertoire of religious intuitions like everyone else. I don't personally subscribe to beliefs in the supernatural, and since I'm not a member of an organized religion, I suppose you could say that I'm not religious. But like I said earlier, it really depends on what you count as religious. I actually think on one level we're all religious, even atheists. People can train themselves to dismiss religious intuitions, but I don't think they can eradicate them.

What kinds of intuitions are you talking about?

The intuition that when people die they're still around in some sense. I think we have that intuition whether we declare ourselves to be religious or not. And the sense of being watched when you're doing something you should feel guilty about. When you see the amazing features of the natural environment—like rivers, marine life, trees in the forest—it's hard not to believe that some creator put them there. Our brains are set up to put a designer in charge of that extraordinary complexity of design. I think we have the intuition that there are supernatural agents around, that they created the world, that we live on after we die. The question is whether we buy into a cultural tradition that builds on those ideas and turns them into something more formalized and doctrinally coherent. I don't myself, but I think a lot of people around the world don't have much choice. If I'd grown up in different parts of the world—for example, in Papua New Guinea, where I did my fieldwork—I'm quite sure I would be religious. It's been interesting to see the decline of organized religion in certain countries, which are usually affluent, safe, and secure. As life gets easier, you could say people get more selfish and less attached to group values.

But if the core impulse of religion is to help us find meaning and purpose in our lives, shouldn't that also apply to affluent societies?

That's true, but the question is how we go about looking for meaning in the world. I personally don't agree with the idea that the main explanation for religion is that we're on a quest for meaning. I think we need to look at what participation in a particular cultural tradition—religious or otherwise—does for the individual and the community. There are lots of different components to religion. But if we're just thinking about the ones that are universal, that seem to be part of our evolved psychology, I don't think innate curiosity and desire to puzzle together the meaning of life explains religion.

And so what does, in summary, explain religion?

Well, it's not a monolithic entity for which we could offer an overall explanation. If we define what we're really interested in—supernatural agents, rituals, afterlife beliefs, creation stories—then we'd find they result from quite different mechanisms and have different evolutionary histories. There just can't be a magic bullet explanation of "religion" as if it's one single thing.

What do you think of the New Atheist critique of religion—not only that belief in God is intellectually bankrupt, but also that religion is dangerous?

It's a difficult question. The New Atheists tend to take a rather shallow view of religion as simply a set of propositions about the world. To understand the power of religion, I think we need to understand what it does for individuals and communities. When the New Atheists consider those sorts of questions, they seem to take a very jaundiced view. They tend to insist that religion makes us do bad or foolish things. And I think claims of that kind are often heavy on rhetoric but light on systematic and balanced observation.

But the New Atheists point out that many people who've committed violence, even terrorism, have done so in the name of certain religious beliefs.

It's possible that's the case. We're currently engaged in a careful study of the phenomenon of self-sacrifice in these sorts of conditions. For example, we went into the revolution in Libya in 2011. One of my students, Brian McQuinn, was holed up in Misrata throughout the siege of that city, studying the groups committed to risking their lives—and in many cases laying down their lives—for the cause. Virtually all of them were Muslims. There were individuals whose job was to chant "Allah is great" as they were engaged in house-to-house combat. The whole system of beliefs and activities was suffused with religion. But while it appears that people are dying for religious causes, I actually think it would be truer to say they die for each other. I think first and foremost we bond with a small group based on our personal ties with individual members. And when we're prepared to put our lives on the line, it's for those people rather than for something as abstract as a religious idea.

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The Family That Couldn't Say Hippopotamus

The origins of language are not what inherited disorders seemed to suggest

BY ELIZABETH SVOBODA

THERE IS A FAMILY living in Britain, known only as the KE family, with a few members that can't quite say words like "hippopotamus." They know the words, but can't get their mouth positions quite right, so their speech comes out garbled. Some family members have a hard time saying words in the right order, and others have trouble reciting words that begin with the same letter. Multiple generations of the family have similar language difficulties, suggesting a genetic basis for their disorder.

In the early 2000s, Oxford University geneticists Anthony Monaco, Simon Fisher, and their colleagues found the culprit: KE family members had a rare mutation in a gene called *FOXP2*.[1] The mutation was subtle—only one nucleotide removed from the typical *FOXP2* sequence—but the resulting language impairment was substantial. That meant there was probably something about the normal *FOXP2* gene that helped enable fluent speech. In the wake of this finding, *FOXP2* was trumpeted in the press as a "grammar gene" and a "language gene."

The labels seemed to fit well with certain longstanding theories about the origins of language. In the mid-1960s, linguist Noam Chomsky proposed that the human brain is equipped with a distinct "language organ"—a module that appeared relatively suddenly in the history of human development. "The language organ interacts with early experience and matures into the grammar of the language that the child speaks," Chomsky told *Omni's* John Gliedman in a 1983 interview.

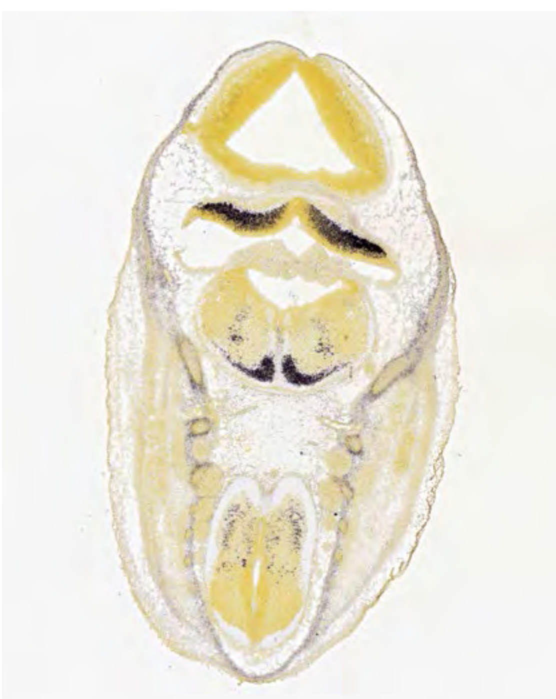
Coming out of an era of rapid advances in computer technology, the idea of a discrete, common origin to human language made intuitive sense. It was also consistent with observations that many languages have similar features, suggesting that the brain contains a limited array of linguistic "switches" that constrain the ways language develops. These narrow paths, according to the theory, give rise to universal language

ILLUSTRATION BY MICHAEL WOLOSCHINOW

structures. In sentences that contain a verb and object, for instance ("Duane played the piano"), a preposition often precedes a noun ("at the party").

But over the years, it became clear that the truth about language origins was not quite as simple as a "language gene" or well-defined language module. Further study revealed that the *FOXP2* gene is relevant to multiple mental abilities and is not strictly a language gene at all. In a 2009 paper, for example, Max Planck Institute geneticist Wolfgang Enard exploited the fact that just three amino acids distinguish the human version of the *FOXP2* protein from that of mice. When he engineered the *FOXP2* genes of mice to produce proteins with the two human *FOXP2* amino acids, it resulted in functional differences in brain areas critical for carrying out fine motor tasks and controlling muscle movements, as well as altered function in regions involved in sending and receiving reward signals.[2]

THE LANGUAGE GENE *FOXP2* is expressed in many areas of the brain, including the cerebellum and hindbrain. It is essential for speech and language development.



"This is the reward system, the system that gets hijacked by drugs," Enard says. "This system is needed for statistical learning. It makes sense to say if you want to have speech, you need to tune it." A later study also found that mice with human *FOXP2* learned faster than regular mice.[3]

The same gene that regulated language so strongly also regulated other mental faculties, so its very existence appeared to contradict rather than strengthen the idea that language commands its own territory separate from other areas of the brain. As Enard points out, the language-as-island idea is also inconsistent with the way evolution typically works. "What I don't like about the 'module' is the idea that it evolved from scratch somehow. In my view, it's more that existing neural circuits have been adapted for language and speech."

In humans, too, evidence is mounting that language relies on a surprisingly broad neural support system. A 2012 paper from the University of Washington shows that infants with denser concentrations of white or gray matter in the hippocampus and cerebellum show higher levels of language skill by their first birthdays, despite the fact that these brain areas have not traditionally been linked to language.[4] Earlier this year, University of Washington scientists also found that 7-month-old babies show activation in a number of different brain regions when they hear speech, including in the cerebellum, which is important for coordinating motor movements.[5]

Some researchers argue that the universality of structures across different languages has also turned out to be weaker than initially thought. In 2011, Uppsala University evolutionary linguist Michael Dunn and his colleagues created computer models of how word order has changed over time in four of the world's largest language groups: Uto-Aztecan, Indo-European, Bantu, and Austronesian. They found that instead of developing parallel structures, each language was evolving according to its own set of rules.[6] One structure that statistical methods suggested was universal (how "verb-object" clauses influence word order in prepositional phrases) actually appeared in just half the major language groups the team studied. "What seems like a strong statistical correlation really only happens in two big [language] families," Dunn says. "It looks a lot less universal."

People making complex tools showed brain blood flow patterns similar to those they displayed when thinking about words.

Dunn doesn't think that a language-specific brain module evolved and gave rise to predictable language structures. Instead, he believes language—in all its messy complexity—emerged once humans reached a certain level of cognitive capacity. "The module thing started with the computer metaphor for the human brain, and I think this was of some use at the time," he says. "But really, it's a little bit deceiving. It's all a much more ramshackle, muddled-up biological system."

QUESTIONING THE EXISTENCE OF a language module would seem to make understanding the origins of language more difficult. Without a neatly packaged module to point to, how can we tell when and how language appeared?

Some clues are coming from studies of the history of toolmaking. In 2010, Imperial College London neuroscientist Aldo Faisal enlisted his colleague Bruce Bradley, an Exeter archaeologist and skilled craftsman, to take part in a novel experiment. Bradley was tasked with whittling blocks of stone, crafting a series of rough-hewn stone flakes and more detailed, symmetrical hand axes, while wearing a glove studded with sensors that tracked his hand movements. When Faisal analyzed the sensor data, he noticed that the hand motions required to craft a well-turned hand axe were basically identical to those needed to make a stone flake.[7]

The results suggested that it wasn't an improvement in manual coordination per se that allowed early humans to make the leap from primitive stone flakes to hand axes—instead, it was a shift in cognitive capacity. This shift, Faisal points out, could also have aided language. An earlier study had reported that when master craftsmen are making complex tools like hand axes (but not simple stone flakes), specific regions of the brain's right hemisphere light up on functional MRI scans—brain areas that are also involved in making sense of speech.[8] Similarly, in 2013 University of Liverpool archaeologist Natalie Uomini found that people making complex tools showed brain blood flow patterns similar to those they displayed when thinking about words.[9]

Researchers like Faisal think that as toolmaking skills became more common in the population, humans may have acquired the mental horsepower requisite for language. "A lot of people would say that toolmaking came [before language]—that's the general prevailing view," Uomini says. "I would just say that they co-evolved."

Even the advancement of general cognitive skill, however, may be too narrow a picture of the evolution of language. University of Edinburgh computational linguist Simon Kirby argues that, while the human brain may be a necessary foundation for language, it is not sufficient to explain it. The beginnings of language, Kirby says, were profoundly shaped by the dynamic interplay of human culture itself.

Kirby took a unique approach to probing the origins

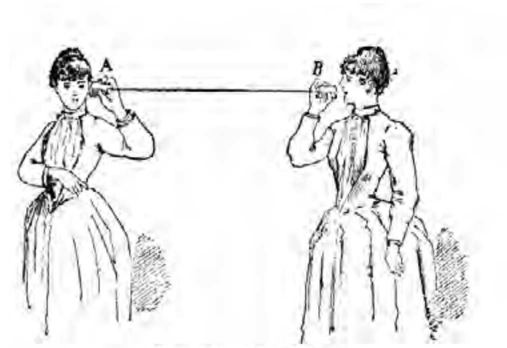


Fig. 76. Trådtelefon.

of language: He taught human participants novel languages he had made up. He and his colleagues showed human subjects cards with different shapes and pictures on them, taught them the words for these pictures, and tested them. "Whatever they do, whether they get it right or wrong, we teach it to the next person," Kirby says. "It's rather like the game Telephone."

Remarkably, as the language passed from one learner to the next, it began to acquire cogent structure. After 10 generations, the language had changed to make it easier for human speakers to process. Most notably, it began to show "compositionality," meaning that parts of words corresponded to their meaning—shapes with four sides, for instance, might all have a prefix like "ikeke." Thanks to these predictable properties, learners developed a mental framework they could easily fit new words into. "Participants not only learn everything we show them," Kirby says, "but they can correctly guess words we didn't even train them on."

Kirby realized that this process of iterated learning—which depended on brain function but extended beyond it—went a long way toward explaining where language structure came from. Having watched in the lab as ordered languages appeared, he's skeptical when he sees colleagues get entrenched in purely biological explanations for language's origins. "There's been this assumption that brain and behavior are related very simply, but languages emerge out of huge populations of socially embedded agents. The problem with 'gene for x' or 'grammar module y' is they ignore how something that is the property of an individual is linked to something that is the property of a community."

This linkage reveals the absorbing paradox at the heart of language's origins. As hardwired as it is, language is a distributed object, both across the human brain and across generations of people. And it is precisely the chaotic hot-potato toss of words and grammar that yields the order and beauty that we see today. In the realm of language, as in other things, modern science is showing us that we are not the pilots of our own sealed ship, but are actors in a play, each able to contribute a verse.

ELIZABETH SVOBODA is a writer in San Jose, California, and the author of *What Makes a Hero?: The Surprising Science of Selflessness.*

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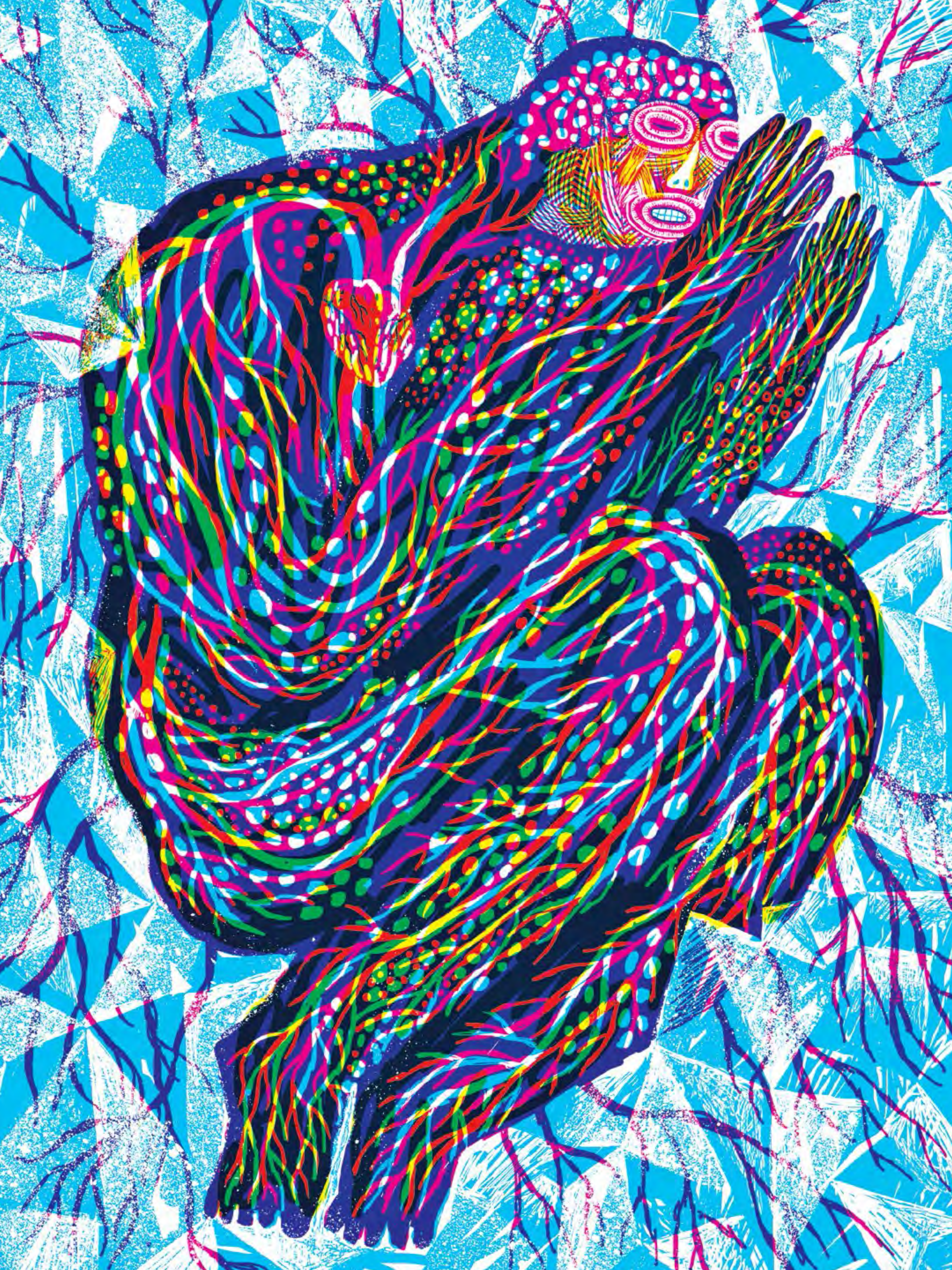
"THE ORIGINAL NATURAL BORN KILLERS"
ILLUSTRATION BY **EDWARD KINSELLA III**



At Death's Door, He Was Put on Ice

How a new technology is resurrecting patients from what was once certain death

BY KIRA PEIKOFF

IN 2007, PATRICK SAVAGE, then a 52-year-old deputy chief of the New York City Fire Department, suffered cardiac arrest after a morning run on the treadmill. He had run triathlons every year since 1984, but a genetic predisposition for heart disease finally caught up with him. At Columbia University Medical Center, doctors performed cardiopulmonary resuscitation techniques, but Savage failed to rebound. Over six hours, Savage's face periodically turned purple, and he experienced seven consecutive cardiac arrests. At one point, Stephan Mayer, a neurointensivist at the Columbia hospital at the time, spoke to Savage's wife, Mary Grace Savage, who worked in his intensive care unit as a nurse.

"He's probably not going to make it," Mayer said. Because Savage had been "pulseless"—his heart stopped beating for a cumulative total of about 90 minutes—he could already have suffered brain death due to oxygen deprivation.

"I know that," Mary answered.

Despite the grim prognosis, the doctors refused to give up. They placed Savage on a heart pump and a ventricular assist device to keep jumpstarting his heart. But they fretted about his brain. Neurons are the most high-energy cells in the body, so the brain can be the first organ to die when oxygen becomes scarce. There was one thing that offered Savage a slim chance: a revolutionary measure called therapeutic hypothermia, which is a resuscitation technique used on cardiac arrest patients who remain pulseless for too long. Patients are cooled to about 90 degrees Fahrenheit, which slows down the body's metabolism and decelerates the process of brain death. The medical team placed sticky freezing pads all over Savage's body and ran a heat exchange catheter through his femoral vein up into the vena cava—the large vein that carries blood to the heart. Through the catheter, they circulated chilled saline solution, which continuously drew heat out of his body.

Throughout history, medical breakthroughs have

ILLUSTRATION BY JOOHEE YOON

shown the body to be more resilient than previously imagined, granting physicians new windows of opportunity to save lives. Only 60 years ago, death was not seen as a process that could be interrupted, but as a moment in time: If your heart stopped, you were gone. Life-support machines, coupled with existing knowledge of CPR, changed that. In 1968, a Harvard Medical School committee outlined new expiry criteria: brain death. Today, a person is legally dead if their whole brain, including their brain stem, has ceased to function, regardless of whether their heart is beating. Thanks to growing insights into cellular function, therapeutic hypothermia has entered the medical arena to revive brain function in those critical moments when "your heart has stopped beating, but your cells are still alive," offers Mayer. It's a complicated, biologically fraught period of time.

Normally, after glucose and oxygen enter a neuron, mitochondria—the powerhouses of every cell—burn them like an engine burning gasoline. Each glucose molecule generates molecules of adenosine triphosphate, or ATP, which power the neuron's metabolism.

> "They're pulseless, they're trying to die, and we're trying to prevent them from dying."

But without oxygen and glucose, ATP can't help pump sodium and calcium out, and the two elements build up. This causes waves of electrical depolarization that sweep across the brain.

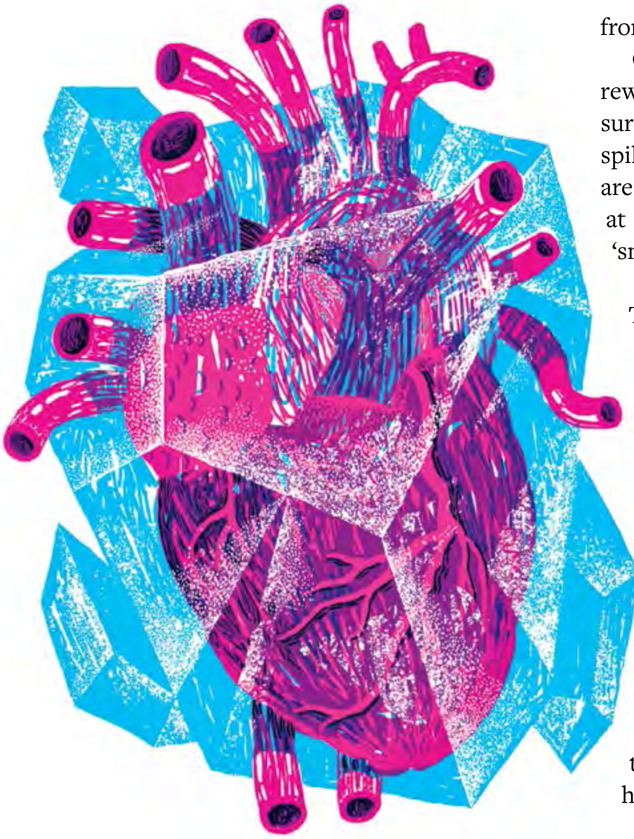
Neurons then start to release glutamate—a neurotransmitter normally present in the brain in small amounts—which in high levels causes extreme overactivation. This puts the neurons on the pathway for programmed cell death: Free radicals form, tissue acidity increases, and peroxide starts to form, which burns holes in lipid membranes. The protein scaffolding of the cytoskeleton, a network of fibers that maintains cell structure, collapses; the cells leak out inflammatory mediators that signal an acute injury to other cells; and the blood-brain barrier starts to break down. Mayer, who today is the director of the Institute for Critical Care Medicine at the Icahn School of Medicine at Mount Sinai, likens the process to the sinking of the Titanic, with water surging faster and faster until the ship reaches a point of no return. "With a final massive influx of intracellular calcium, that's the last nail in the coffin, and you're done," he says.

But neurons don't die instantly. Different cell populations in the brain have different thresholds of tolerance for a lack of oxygen and glucose. After an oxygen supply interruption of 10 or 15 minutes the brain can recover pretty much normally, though some neurons will die, which could cause some memory loss. Depending on how low the flow of oxygen is and how slowly the brain burns it, cells can remain alive for hours, as medics now understand. Cooling reduces the energy requirements needed to maintain cells' integrity, which extends their lives. Paradoxically, the return of blood flow after a period without oxygen can also damage cells, so slowing down metabolic processes during recovery helps the brain, too. "It's like your brain is smoldering on fire and hypothermia is like throwing water on the fire," Mayer says.

Now doctors at the University of Pittsburgh are taking therapeutic hypothermia to (literally) a new degree in humans. In a recently started clinical trial led by Samuel Tisherman, the director of the Surgical Intensive Care Unit at the University of Maryland, doctors cool victims of violent trauma to about 55 degrees Fahrenheit. At that temperature, the human heart cannot beat. But, Tisherman explains, the potential benefit of the chill makes it a risk worth taking.

In the United States, nearly two-thirds of deaths in people under the age of 34 are due to injuries and violence. Victims of violent trauma bleed out in minutes—too quickly for surgeons to repair their wounds. Similar to cardiac arrest patients, their brains also suffer oxygen deprivation, but they have little blood left to pump. "In cases of sudden cardiac death, the heart is still full of blood, so you can keep it pumping through CPR and extend time," explains Hasan Alam, head of general surgery at the University of Michigan. "But in bleeding situations you don't have that."

Instead, trauma patients are infused with chilled saltwater, the approach Alam helped pioneer in pigs. In this cutting edge technique, called Emergency



Preservation and Resuscitation technique, or EPR, the surgeons place a catheter into the aorta going up to the patient's head. Saline solution is pumped directly into the veins to rapidly cool first the brain and then the body. This lets doctors stop the clock and buy time until a patient's bleeding can be controlled. At 55 degrees, the body uses as little as 4 percent of the amount of oxygen it would normally need, and is able to tolerate not having blood flow for a couple of hours. In Alam's lab, the longest time that a pig remained temporarily dead, having bled out for 20 or 30 minutes, before being successfully revived, was three hours. The Pittsburgh team, however, doesn't view their patients as dead, even temporarily. "We don't really want to think of [these patients] as being dead," Tisherman says. "They're pulseless, they're trying to die, and we're trying to prevent them from dying."

Once the wounds are repaired, the patients are rewarmed gradually—otherwise their blood pressure would fall and their intracranial pressure would spike, causing "permanent" death. Once patients are rewarmed to 90 degrees Fahrenheit, they are left at that temperature for up to 12 hours, so that their 'smoldering" brains can revive slowly.

"The technology is evolving as we speak," says Thomas Scalea, physician-in-chief at the University of Maryland's Shock Trauma Center, which will soon be joining Pittsburgh in the clinical trial. The prototypes of the cooling cardiopulmonary bypass machines currently being developed at the center are the size of soda cans, and are "pretty slick," he says. These machines give medics a greater window of opportunity to save lives. "It's much, much longer than the four-minute barrier that we once thought we had," says Lance Becker, the director of the Center for Resuscitation Science at the University of Pennsylvania. "As we learn more about the very nitty-gritty of the metabolism, we can come up with better and better ways of restarting a stopped brain and a stopped heart."

Deputy Chief Savage was fortunate—both his brain and his heart successfully revived. About a week after he was rewarmed, a nurse practically fainted from shock when she saw him walking.

He has still not missed a triathlon.

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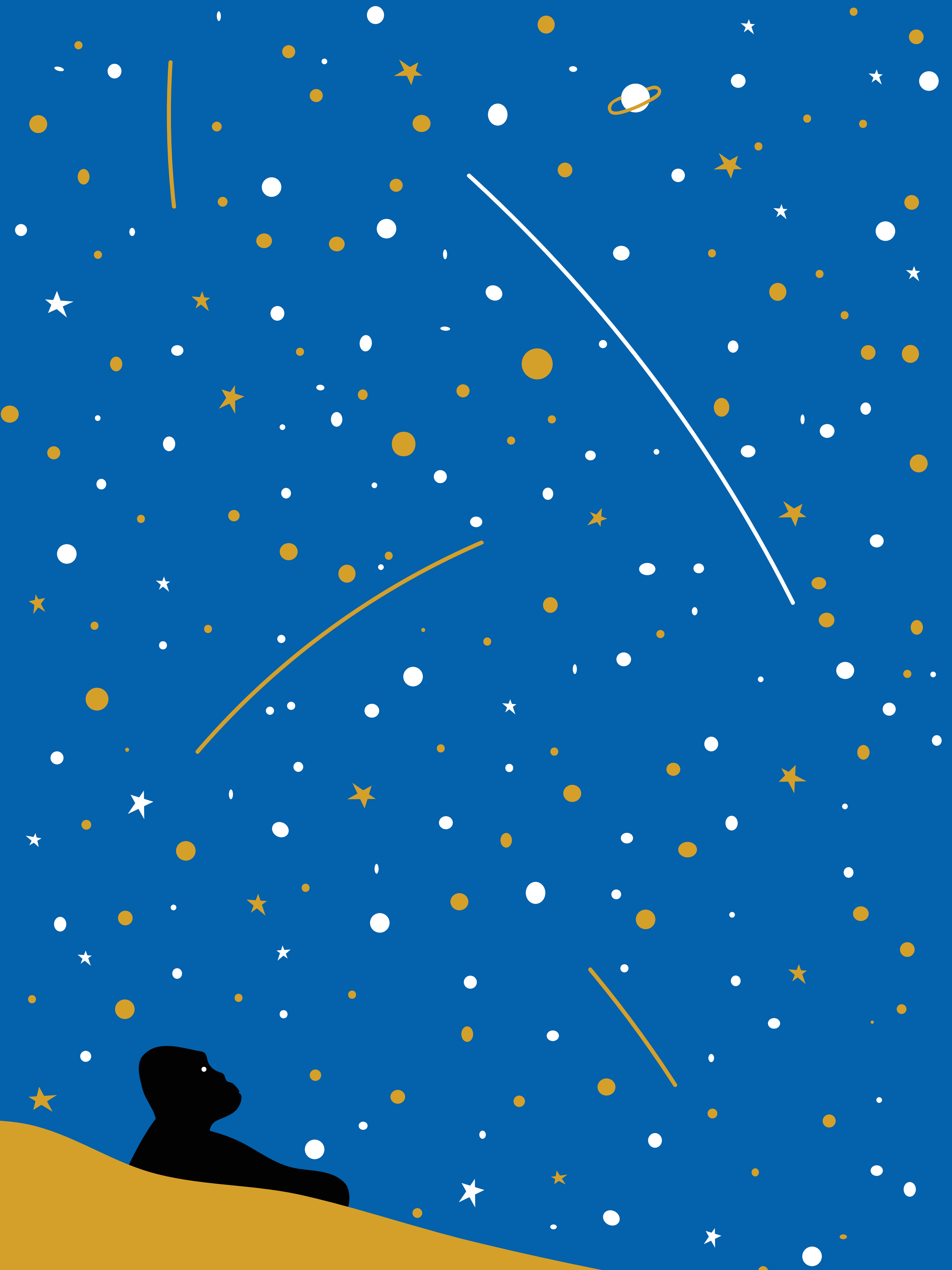


Digging Through the World's Oldest Graveyard

In Ethiopia, paleontologists are pushing back the clock on humanity's origins

BY AMY MAXMEN

PHOTOGRAPHY BY THE AUTHOR

TWO HAMMERS, TWO SHOVELS, four rifles. They carried their own tools. Zeresenay Alemseged, a young and driven Ethiopian fossil hunter, joined by four armed soldiers and a government official, was on a mission to the Afar Depression, a region shaped like a tornado in Ethiopia's Great Rift Valley. The Afar is bone-dry, scorching hot, and riddled with scorpions and vipers. It is regularly shaken by earthquakes and sinking deeper into the Earth as the converging tectonic plates beneath it pull apart, and molten magma bubbles up through the cracks. When the magma cools, it forms sharp, basaltic blocks.

Along the road, the boulders blocked Alemseged's path. He had to stop the car, lift the boulders, drive further, repeat. Dry riverbeds were smoother, but frequently the tires sank in the fine sand, and the men, sweating in the afternoon sun, pushed the jeep onward.

Alemseged was headed to the most dangerous spot within the Afar, which even Indiana Jones-types avoided because of constant conflicts between local tribes. The armed soldiers were his security. Alemseged had no salaried scientific position, and refused to accompany teams led by accomplished researchers going to safer areas with fat grants. If he struck out on his own, he felt sure he could discover academic gold: ancient traces of humankind's past. This meant funding the expedition out of pocket. "I was the driver, so I didn't need to pay a driver; I was the cook, so I didn't need to pay a cook; and I was the only scientist," Alemseged said.

His aim was to explore an area called Dikika, across from a bank on the Awash River where an American paleontologist, Donald Johansen, had discovered Lucy in 1974. Her ancient skeleton's partially human, partially chimpanzee features were a clear indication of our descent from the apes. Dikika was the logical next place to look for more fossils, but no one had done so because of the risk presented by battles waged over water and land between the Afar and the Issa, pastoral

ILLUSTRATION BY OLIMPIA ZAGNOLI

tribes who inhabit Dikika. But Alemseged, who goes by Zeray (pronounced Zeh-rye), was not deterred.

Alemseged's bare-bones team reached a vast plain of sand and volcanic ash. He knew this sediment yielded the type of fossils he was after. In December of 2000, one of the men spotted the top of a skull the size of a small orange in the dirt. Slowly, over a period of years, he and his colleagues carefully unearthed a petite skeleton of a child who had likely died in a flood and been buried in soft sand, 3.3 million years ago. She was a member of Lucy's species, *Australopithecus afarensis*, from a period about halfway between today and the time when our lineage went one way and that containing chimpanzees went the other. In 2006, Alemseged and his colleagues published their findings in *Nature*.[1]

The child was named Selam—a word for peace in several Ethiopian languages, a wish to end the fighting in Dikika. Selam's gorilla-ish shoulder blades and long fingers betrayed a penchant for swinging on braches. But bones at the base of her head showed that she held it upright and therefore walked on two legs. The size of her skull suggested her brain developed slowly through early childhood, a distinct characteristic of humans from long before modern humans evolved.

"It's the earliest child in the history of humanity," Alemseged said, enunciating each word slowly. "That discovery was 100 percent Ethiopian. It was by Ethiopians, on Ethiopian land, led by an Ethiopian scientist."

Alemseged, 45, was describing his scrappy first expedition to Dikika for me in a sparsely furnished conference room in the new facility for "antiquities research and conservation" beside the National Museum in Ethiopia's cool, green capital, Addis Ababa. It was August and the facility was a hub of activity. Some of the world's foremost experts on early human evolution rushed from room to room, hurrying to collect data from their fossils before the school year started. They were here, instead of in the field, because heavy seasonal rains had flooded the dry riverbeds on which they normally drive to the Afar.

Alemseged wore two beaded bracelets on his wrist—one with the word Ethiopia spelled out in yellow beads on a black background. With his square jaw and confident demeanor, he looked more like a Hollywood actor playing an archeologist than the serious scientist that he is. When he's not doing fieldwork in Ethiopia, he directs the anthropology department at the California Academy of Sciences in San Francisco, where he lives with his wife and two kids.

I had come to Ethiopia in search of my own deep vision of humankind's history and fate. A flood of new discoveries coming out of the country have suggested that human traits occurred in ancient members of our tribe, the hominids, long before *Homo sapiens* entered the scene 200,000 years ago. I wanted to meet the native and foreign scientists responsible for shifting our origins backward in time. Soon after I arrived, Merkeb Mekuria, an anthropologist and curator at the Ethnological Museum in Addis Ababa, greeted me. "Welcome home," he said.

CHARLES DARWIN KNEW HUMANS evolved from apes, but he died before the fossils that prove our connection with primates most strongly had been discovered. In *The Descent of Man* he wrote, "Those regions which are the most likely to afford remains connecting man with some extinct ape-like creature, have not as yet been searched by geologists."

A century later, Lucy helped confirm Darwin's conjecture. By that time, a vision of our origin had been born, and her skeleton was assumed to fit the story. It's one that (wrongly) persists today: Apes climbed out of the trees and ambled onto their feet, dragging their fists, as the climate warmed and turned forests into grasslands. Yet it was clear to paleontologists that many more fossils were needed to test this hypothesis. That's around when Ethiopian paleontology by Ethiopians got started in earnest.

The bones of distant members of our human family are buried in tumbles of sand in Africa, and Ethiopia has unbeatable archives. The pages of human prehistory are preserved in its layers of mud, bones, and basalt. In the Afar, the magma that periodically bubbles to the surface serves as a timepiece because the chemical composition of every volcanic rock betrays the stone's age. Over time, the ratio of the gases trapped within it changes at a fixed, known rate, so you can determine whether it covered the land 4 million years ago or yesterday. Fossils located between two layers of volcanic ash and lava were left by animals that lived within that time range. Individuals belonging to Lucy's and Salem's species have been found in layers dating from

FOSSIL HUNTER Paleoanthropologist Zeresenay Alemseged beside his discovery, a 3.3-million-year-old child from an early species in humankind's lineage. "When you realize that you, as an individual, are part of a very long line, you begin to take it personally," he said. "You really are afraid to cut off that line."

almost 4 million to 3 million years ago. That means they lasted five times the duration of our own species so far. "Can we do at least as good as this primitive species?" Alemseged asked.

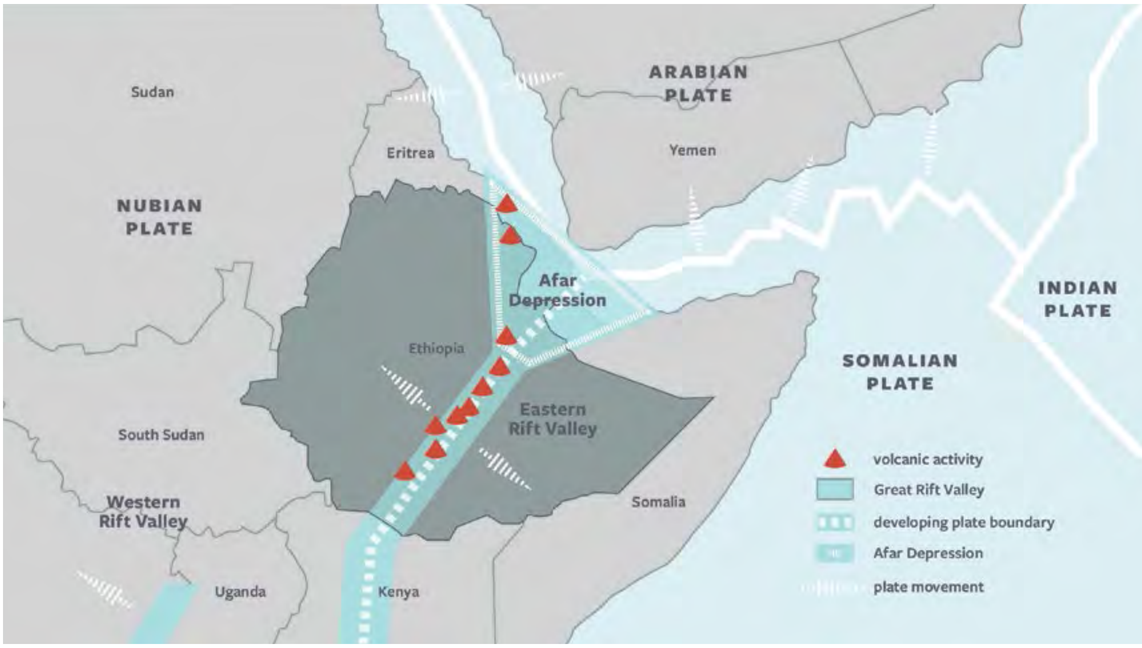
In 1978, a student at Addis Ababa University, located in Ethiopia's mountaintop capital, was told to summarize the information on fossils discovered by Western scientists in the Afar. The student, Berhane Asfaw, had not chosen the job. It was assigned to him—as jobs were in those days—by the Derg, the communist regime that ousted the long-standing Ethiopian emperor Haile Selassie, and threw Asfaw, and thousands of other dissenters, in jail. Of six students locked up alongside Asfaw, five were executed. Asfaw was set free.

Asfaw found solace in the geology and archeology reports he combed through. Desmond Clark, a geology professor at that time at Addis Ababa University, observed that Asfaw had done a thorough job, and convinced him to pursue a graduate degree. Clark invited his mentee on an expedition to the Afar with Tim White, then a skinny, ambitious junior faculty member at Berkeley. Before the trip was over, what had begun as an assignment had become Asfaw's life passion.

"Every second, I was learning," Asfaw recalled, his palms swinging upward along with his thinning eyebrows. "I had been a geology student so I knew which rocks were old, but it was such a surprise to see fossils coming out of the sediments. It wasn't just one or two, there were plenty, and I saw hand axes, and just hundreds of stone tools." Asfaw was impressed by White, now a leading expert on early human evolution. "He was so hyper, he never got tired," Asfaw said. The duo got along swimmingly. By 1981, Asfaw was off to Berkeley to finish his Ph.D. Soon after, his young wife followed. They appreciated Berkeley's diverse and liberal community. On Telegraph Avenue, they giggled at the town's notorious bohemians.

Meanwhile, between 1983 and 1985, the Derg amplified the devastating effects of a great drought, in which 1 million Ethiopians starved to death. Most Americans learned about the tragedy in TV ads of skeleton-thin children, and Michael Jackson's "We Are The World," and Band Aid's "Do They Know It's Christmas." "When I saw all those people gathering to try and raise money to help the affected people, I really felt criminal to be on the outside and not doing anything," Asfaw explained. "My dream was to come back to Ethiopia and make a difference."

By 1988, the Derg's collapse was imminent, and Asfaw was eager to return home. "My plan was to survey the entire Rift Valley from north to south and look for new [fossil] sites," he said. During the transition from the Derg to the new government, the country became increasingly unstable, and there was growing conflict near the northern Eritrean border. Asfaw kept thinking about the precious hominid fossils that could be lost before they were ever found. He stressed the urgent need to preserve antiquities in grant proposals. With funds from the National Geographic Society, Asfaw organized a team including White, a Japanese friend from graduate school, Gen Suwa, and a handful



HOTSPOT The intense geological activity in Ethiopia's Great Rift Valley makes it one of the world's best places for the study of early human evolution because volcanic rocks can be dated, putting a time-stamp on every fossil. Three tectonic plates converge in the Afar Depression in Ethiopia, where several hominids and stone tools have been found. As the plates spread apart, magma from miles below the surface bubbles up through volcanoes, and the land sinks. In millions of years, the Nubian and Somalian plates will separate completely, and ocean water will fill the space between them. Africa will then be two continents instead of one.

INFORMATION PROVIDED BY GIDAY WOLDEGABRIEL, LOS ALAMOS NATIONAL LABORATORY / ANDREA GOTTARDY

of young geology, archeology, and history graduates from Addis Ababa University. By the end of the year they were off. "It was the first team with a lot of Ethiopian researchers," Asfaw said. "We were successful because we knew how to get around and which areas to avoid."

At one of the sites, Suwa stumbled upon the shiny surface of a molar that was distinctly hominid. Much older than Lucy, the team called the genus *Ardipithecus ramidus*, based on the Afar word *ardi* for "ground," and *ramidus* for "root." They thought the species might be the first member of our family to walk on land on two legs.

Then in 1994, one of the young Ethiopians on the expedition, Yohannes Haile-Selassie—who has since become a paleoanthropologist at the Cleveland Museum of Natural History—spotted a finger bone from *Ardipithecus ramidus*. The team decided to excavate the entire region, and recovered over 100 fractured pieces of a single skeleton, bones from several other individuals, and fossils of ancient animals that lived within the same period, 4.4 million years ago. That's when the real work began.

At first, the team kept their fossils in the National Museum in Addis Ababa. When it overflowed, they moved them to a canary yellow, stucco building beside the museum, which had housed the Italian government during its brief occupation of Ethiopia around 1940. There, and in an "old moldy building" beside it, White removed hardened silt from soft bones with brushes and dental tools; Suwa took fractured pieces of the skull to Japan where he digitally reconstructed their arrangement with a computed tomography scanner; and Asfaw compared the skull with those of ancient primates and hominids from around the world. During the course of the analysis, a skull from an older member of our ancient family was reported from Chad, but the rest of its skeleton was missing. From start to finish, the analysis took 15 years and 47 researchers to paint a full picture of *Ardipithecus ramidus*—Ardi, for short—and her surroundings. In 2009 they published 11 reports in the journal *Science*.[2]

The following year, a brand new, five-story facility for antiquities research and conservation, funded by the Ethiopian government, opened its doors in Addis Ababa. In part, this happened because of years of advocacy from Asfaw and his Ethiopian colleagues, who regularly spoke with the government about the importance of human evolution research. Grants from the United States, Japan, and France helped furnish the building and stock it with equipment. Casually called the museum facility, it abuts the old Italian government building and houses more than 250,000 ancient bones and stone tools, including 11 species of hominids—half of them discovered in the past two decades.

"Berhane deserves a lot of the credit for changing the way things are done, from the old colonial way where Westerners gained access to the countries with these resources, and got publications, but never invested in local scholarship," White said. "That's a lose-lose situation because the country loses and so does the science—which is done very well by folks who speak the local languages, know the geography, and understand the culture."

However, Ethiopia is still a long way from Berkeley. The electricity frequently goes out, which means Asfaw must leave his office when the sun dips below the horizon. The phone lines are dreadful; the Internet spotty. This disconnect to the rest of the world may explain why Asfaw is rarely mentioned in magazine articles and books on human evolution, despite his dozen publications in top journals. He's been offered academic positions in rich countries, where he would obtain a good salary and wider recognition, but he declines. I asked why and he answered with a grin. "I am the most privileged person because I live with the fossils," he said.

WITH ARDI, A COUPLE of existing views went up in smoke. Lucy's predecessor was supposed to represent an earlier step in the chain, an ape-man who hobbled through the type of savannah advertised on Safari brochures. On the contrary, Ardi appears to have been a bona fide bipedal woodland dweller. Monkeys and other woodland mammals unearthed where Ardi and her kin were buried indicated that the species spent their days in the woods. Ardi's big toe remains chimpanzee-like. It's large and opposable, allowing her to climb along branches. But unlike apes, her toes are arranged in line with her foot to help her step flatly on the ground, and her pelvis is broad enough to anchor walking muscles.

> As I traveled through Ethiopia with scientists and local guides, dodging thick sheets of rain in Addis Ababa, I realized just how fragile the scattered remains of our past are.

"The savannah hypothesis was perfectly reasonable, until it was like, 'Oh crap, there weren't grasslands,' " said Amy Rector in the museum facility in Addis Ababa, where she was surrounded by ancient antelope skulls, their long, twisted horns extruding from wooden boxes. Rector underscored another debunked scenario: the idea of a linear progression of humankind. Two years ago, the discovery of sausage-toed foot bones that match Ardi's, in layers of rock from *Australopithecus*' time, show that a range of upright-walking species occurred simultaneously for hundreds of thousands of years.

Rector, an anthropologist at Virginia Commonwealth University, often does field work in Africa, and keeps her fossils in the Ethiopian museum facility. She

RIFTING APART Our earliest ancestors inhabited Ethiopia's Great Rift Valley. Fractures in the Valley grow as the tectonic plates underlying the region drift apart.

reconstructs the context in which our ancient family members evolved by studying the animals surrounding them. "I ask myself what hominids might have seen in the area where they slept," she said. "What did they see when they woke up, what was going to eat them, where did they run to get away?"

Around 3 million years ago, Rector said the climate appears to have warmed slightly. Some of the forests likely gave way to grasslands. But the environment, as a whole, was as mosaic as it is today in Ethiopia. *Australopithecus* specimens have been found around everything from woodland creatures, to grass-grazing ancestors of antelopes and gnus, to ancient hippos, crocodiles, and fish.

Back then, the sinking lowlands of the Eastern Rift Valley would still have been rather flat, and fed by rivers flowing down from the mountains, and the occasional land-locked lake. Walls of grey, silica-rich boulders, which formed as molten lava cooled, would have been younger than they are today, less worn by wind and rain. Ashen black mounds—created as magma ejects out of vents in the Earth—would have existed also, but their location would have been different. Those seen today along the southwest corner of the Afar Depression, where three tectonic plates collide, have formed within the past several hundred years. Within a day or three, Lucy might have walked past smoldering volcanoes on this dynamic landscape, grazed on berries growing beside crocodile-infested lakes, and then continued into the green highlands, in search of food, mates, or a safe place to rest.

During one afternoon, Lucy might have come across the fresh carcass of an antelope. Famished for a meal beyond insects and roots, she might have paused to examine its succulent flesh. But at less than 4 feet tall, she would have been no match for a pack of hyenas, cackling in the distance. With a mix of hunger and fear, might she have grabbed a sharp stone, and torn

CLOCKWISE FROM TOP LEFT

HEADS UP The 4.4-million-year-old skull and skeleton of our ancient ancestor, *Ardipithecus ramidus*, found in Ethiopia, revealed the upright origins of humankind.

IMAGINING THE PAST Ancient antelope skulls stored in the research facility beside Ethiopia's National Museum reveal that some of our earliest ancestors inhabited woodlands.

CHANGING LANDSCAPES A 3-million-year-old fossilized fish from the arid Rift Valley suggests that the area's hominids lived beside rivers, which have since dried up.

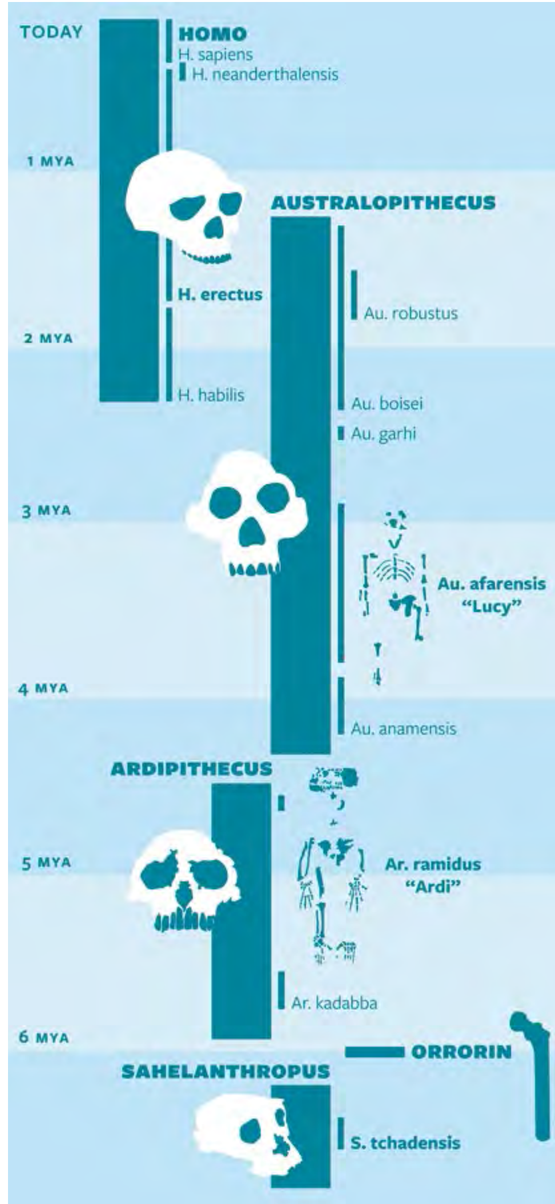
chunks of flesh from the beast's bones that were small enough for her to run to safety with, yet large enough to warrant the risk? After thousands of years of various individuals doing just this, might some of them have learned how to bang one rock against another and make their own sharp stones to carry?

To Alemseged, these scenarios are not far-fetched. After all, our cousins, the chimpanzees, stab termites with twigs, and orangutans hold leaves above their heads like umbrellas when it rains. But the oldest known stone tools hail from 2.6 million years ago, long after *Australopithecus afarensis* appears to have gone extinct. Archeologists have long attributed the creation of these tools to our closer kin in the genus *Homo*.

In 2009, Alemseged realized archeologists might have been searching for stone tools with a biased image in mind. In the museum facility, he pointed to the iPhone on his desk. If you were to look for proof of telephones a century ago, he said, you'd miss them if you expected them to look like this. That year, Alemseged mounted another expedition to Dikika—this time with five jeeps and a team of 50. By then, Alemseged held his current position at the California Academy of Sciences. His team was examining bones from animals in Dikika, searching for signs of action on the land when *Australopithecus afarensis* walked it. Punctures in the bones revealed that crocodiles had been voracious, and cracks whispered of antelope herds. But the causes of other scratches were unclear.

In particular, a rib from a large cow and a thighbone from a small antelope bore marks that experts using electron microscopy identified as different from the rest. A sharpened stone, they said, could account for their width, shape, and angle. And radiometric dating techniques confirmed that the marks had been etched more than 3.39 million years ago, in the time of *Australopithecus afarensis*. In *Nature*, Alemseged and his colleagues reported the first signs of butchery.[3] According to the paper, the marks are "unambiguous" evidence of stone tool use, 800,000 years earlier than when paleontologists thought it arose. "This is the first technology," Alemseged said. "It's the invention of something with the idea that it will serve some future purpose."

The finding shocked the archeology world. But Alemseged saw no reason why it should have. *Australopithecus*



FAMILY HISTORY Of about 20 known hominid species, half have been found in Ethiopia. Only a fraction are pictured here. Lucy's species, *Australopithecus afarensis*, survived for about 1 million years, which is longer than humans have existed (MYA stands for "millions of years ago"). Recent studies also suggest it was far more advanced than previously believed.

FOSSIL COMBAT Archeologists debate about the features of a new discovery, a fragment of an ancient hominid, in Ethiopia. Clockwise from left: William Kimbel, Zeresenay Alemseged, Gen Suwa, and Berhane Asfaw.

INFOGRAPHIC BY ANDREA GOTTARDY

afarensis' human-like hands, with long, dexterous thumbs and short fingers, would have allowed them to manipulate stones. What's more, they may have possessed the intelligence to do it. Alemseged's colleague, Dean Falk, an anthropologist at Florida State University, measures the size and shape of the insides of skulls, to get a sense of what ancient hominid brains looked like. Her preliminary studies on *Australopithecus afarensis* suggest their brains were relatively advanced compared with apes' brains, with an expanded area in a front region of the brain called the prefrontal cortex—an area where intentions are processed.

With a higher functioning brain, our ancestors may have had the cognition to create rudimentary technology. The action represents a definitive change in mental processing. "You need a plan, you need the motor skills to do it, you need to keep the task in mind for as long as it takes, and you need the motivation to go to all that work in advance of when you need the tool," Falk said. "That's all frontal lobe stuff."

If individuals had the foresight to make stone tools, they might have also had the ability to teach one another how to do it. The transfer of complicated information among groups could signify another pivotal moment in our evolution, the origin of exceptional "social-cognitive" intelligence: the ability that builds culture among social groups. Other tool-wielding animals, such as orangutans and dolphins, show a degree of social intelligence—but humans are far better at it. When given a battery of social-cognitive tests, such as producing a gesture to retrieve a reward, 2-year-olds outperformed adult chimpanzees and orangutans. The children succeeded in about 74 percent of the trials, twice as often as primates.[4]

More directly, stone tools gave our ancestors access to protein-rich food, which would have been essential to the growth of hungry, big brains. Although the brain comprises just 2 percent of our body weight, it demands about 20 percent of the energy we expend each day. A bigger brain would have helped hominids build better tools, and pass their knowledge on to pack members, and down through the generations. It's a speculative chain of events, but the best hypothesis yet. "The emergence of stone tools is a big bang," Alemeseged said. "The moment you start walking on two legs, the moment you start farming, the moment you domesticate the dog, these are major landmark moments in our history, which made us who we are today."

However, there's a lag in this chain of events if stone tool use began with *Australopithecus afarensis* some 3.4 million years ago. Drastically larger brain sizes didn't occur until about 2.5 million years ago, in our closest kin in the genus *Homo*. Shannon McPherron, an archeologist at the Max Plank Institute for Anthropology, who co-authored the report with Alemseged, said the gap might have occurred if various individuals figured out how to use stone tools independently, repeatedly over time, but never passed the knowledge on.

In this scenario, the fidelity of information-transfer improved over hundreds of thousands of years. By the time *Homo* produced hand axes—oblong stones sculpted into a point, with a base that fits snugly into your palm—they were learning the craft from one another. The consistency in shape and style, as well as in abundance, is interpreted as evidence.

White is not convinced of Alemseged's supposed signs of butchery. He believes crocodiles, not hominid tools, made the marks in the animal bones. Another skeptic is Sileshi Semaw, an Ethiopian archeologist at the National Center for the Investigation of Human Evolution in Spain, who co-discovered the oldest stone tools from 2.6 million years ago. White and his colleagues found signs of butchery from the same period. "Right after 2.6 million years, we have stone tools, cut marks on animal bones, the expansion of cranial capacity, and the emergence of our genus, *Homo*," White said. "These things seem to be correlated."

Alemseged responded to the criticism by suggesting his colleagues may be fighting to keep their stories intact. "The resistance is not based on scientific grounds," he said. In the museum facility, his team sorts through piles of rocks and bones collected in Dikika, in search of more evidence. His colleague, William Kimbel, director of the Institute of Human Origins at Arizona State University, who works in the region where Lucy was found, is doing the same. With a cadre of young Ethiopian and international students now trained in the new facility, more paleontologists will be scouring Ethiopia than ever before. "Mark my words, we will find stone tools from 3.4 million years ago," Alemseged said. "I can't tell you where exactly they will be, but they will be discovered."

AS I DISCOVERED DURING my trip to Ethiopia, the field researchers love to argue. Questioning assumptions as new evidence comes to light is, after all, the sport of science. One afternoon, Alemseged, Asfaw, Suwa, and Kimbel were going at each other over a splinter of hominid skull. Suwa mangled an English idiom in an attempt to describe his objection to Kimbel's opinion; Asfaw stared at his friend of 30 years apologetically, unable to recall the phrase.

Even in their most acrimonious moments, field researchers form a tight-knit community based on respect for one another's full-body approach to science. Their colleagues in offices, who run molecular and digital analyses of fossils, may not appreciate the effort that goes into unearthing the fossils in the first place. "They don't know that the jeep broke down in the desert, and the driver fixed it on his back with an armed guard protecting him, and scorpions beneath him, and he got malaria," White said. Without field research, we'd still be telling a story about how crouching apes progressed to standing man against an imaginary savannah backdrop. We'd lack the fossils to tell us that elements of humanity began millions of years ago in a mosaic of environments.

As I traveled through Ethiopia with scientists and local guides, dodging thick sheets of rain in Addis Ababa, driving past Chinese manufacturing plants outside the city, and into the Afar, where I was parched, hot, and hungry, I realized just how fragile the scattered remains of our past are. They are constantly under threat by development (as African countries mine and modernize), conflict (as political situations shift), and global warming (as floods and droughts increase in severity). Ironically, our exceptional tool-making skills now threaten to lead us toward eventual demise.

When considering how long the oldest members of our family survived before they went extinct, it's impossible to not reflect on our species' fate. "When you realize that you, as an individual, are part of a very long line, you begin to take it personally, you really are afraid to cut off that line," Alemseged said to me one evening. "But I am not pessimistic because humans are arguably the smartest species. We have the ability to reverse the damage we've done, and push things forward."

Travel for this story was paid for by a grant from the Pulitzer Center on Crisis Reporting in Washington, D.C.

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The Wild, Secret Life of New York City

Get back to nature, right in your own neighborhood

BY BRANDON KEIM

EARLY THIS SUMMER I met a friend for breakfast at a restaurant in Williamsburg, Brooklyn. While waiting for him to arrive I spent some time staring at a lot next door—a vacant lot, as the spaces are called, but also the block's one concentrated patch of greenery. It was scraggly and unremarkable, but a welcome respite from the neighborhood's densely packed brownstones and sunbaked pavement.

Afterward we walked to the old Domino Sugar factory, located on the banks of the East River, a once-industrial zone that's passed through gentrification and into the luxury development phase. Near the factory was a small park, previously the site of another vacant lot. On it the local hipsters had erected a giant teepee, outside of which a young woman explained that the park would soon be replaced by condos. When the bulldozers came, she hoped the teepee could be raised elsewhere. There was a vacant lot nearby, on the corner of Bedford Avenue and South 4th Street. "Right now," she said, "there's nothing there at all."

As it happened, that was the lot I'd just been enjoying. And while there were no buildings on the lot, and plenty of space for a teepee, there was certainly not nothing there. Compared to its surroundings, it was positively bursting with life: a pocket grassland where the hand of human development had skipped a beat. It was even a bit wild, a space where life exists independently and spontaneously, rather than being paved under or converted to some approved purpose.

The young woman could hardly be blamed for not noticing it. Not many people do. We are in the habit of seeing untended nature as a sort of blankness, awaiting human work to fill it. It's right there in the name: vacant lot. A place where spontaneous life is invisible, or at best considered so many weeds, the term used to lump together and dismiss what thrives in spite of our preferences.

It's natural for us to elide the existence of what we don't notice, but when we do, we cultivate our own subtle form of emptiness. In cities, so-called vacant lands

ILLUSTRATION BY JORGE COLOMBO

account for a sizable portion of our urban space: roughly 15 percent in most cities and about 6 percent in New York City. That's a whole lot of life we're not noticing.

Cities contain green spaces, of course. And New York contains two of the best: Central Park in Manhattan and Prospect Park in Brooklyn. But parks are destinations, manufactured for experience. They are places to go on a weekend, or a lucky work-free afternoon. Vacant lots are part of our daily surroundings. They are found in places where a property owner waits for the right deal, at the edges of roads and train tracks and parking lots, the liminal zones nobody can be bothered to beautify.

Even nature lovers don't much care for these places. If they notice them at all, they see them as something to restore and reclaim. They're not a significant piece of nature, like a wetland or a forest. Instead they represent unfulfilled potential, as recreational spaces or ecosystem service-providers or simply a nature more to our tastes. Something ought to be done with them.

Yet there are other ways of perceiving vacant lot life. They have their own ecologies, well-suited to urban conditions, and possess a surprising, even lovely richness. They're where you can hear crickets and songbirds on the way to work. They're alive, and alive with the lessons of wildness: that humans are members of life's communities, a neighbor rather than an owner. "This ethical idea," wrote environmental historian Roderick Nash, "may be the starting point for saving this planet."

It's a starting point that begins in our own neighborhoods. Environmentalists proclaim the virtues of living in cities, leaving space for nature outside them. That nature will only be allowed to flourish, however, if we respect it. It's a lesson to learn not from wilderness vacations, wildlife documentaries, or weekend visits to the park. It's a lesson to learn from everyday habitats, even in New York City. It begins with taking a close look.

WHEN I FIRST SAW the Williamsburg lot, I recognized a few of the species—horseweed, for instance—from an ill-fated attempt at seed-bombing my own block's vacant lot. (The seeds failed to penetrate the weeds, the dense existence of which I'd somehow overlooked.) So my recognition of the Williamsburg lot's vitality was a coarse sort of appreciation: a step up from considering the lot empty, but far from acknowledging it in any detail.

"You can't understand anything about plants until you know what their names are," said Peter Del Tredici, a botanist at Harvard University's Arnold Arboretum and author of *Wild Urban Plants of the Northeast: A Field Guide*, indispensable to any city naturalist. "Even biologists don't bother to learn the names. They just consider them weeds. That lets you ignore and disregard them." I called botanist Marielle Anzelone, founder of New York City Wildflower Week, an annual event that teaches people about the city's unappreciated flora, and especially its rare flowers. Anzelone is herself quite rare: someone who can walk down a street and put a name to just about every tree and flower and blade of grass.

We started our walk beside the fence along Bedford Avenue. Through Anzelone's eyes the undifferentiated green came into focus. Old stems of goldenrod ran along the fence. There was horseweed and low-growing field pepper and broadleaf plantain, anthered stems growing from ground level leaf rosettes. Wood sorrel, pokeweed, boneset, and white snakeroot, its leaves whorled with trails left by larval insects. Japanese knotweed and Japanese brome, daisy fleabane, calico aster. Trailing over a cinder block were the vines of a Virginia creeper. Inside the lot, Anzelone found Boston ivy growing along the building, underneath the graffiti, along with sapling zelcova and pin oak trees. She identified more field plants: yellow-flowered black medic, a thorny clump of bull thistle, a patch of clover.

Whenever she found a native plant, one that could trace its lineage deep into the region's evolutionary history, a note of excitement crept into Anzelone's voice. For her, nativity is bound up with a sense of place, of rooting oneself beneath the froth of the contemporary. A clump of path rushes—a species that grows from sidewalk cracks—might conceivably trace its ancestry to seeds that took root when the great Laurentide ice sheet receded 20,000 years ago, leaving behind the essential features of New York City's present geography.

Only a few of the plants in our lot were properly native, though. Most originated in Europe and Asia, arriving in the last few centuries with settlers, or

THE "NOTHING" THERE We are in the habit of seeing untended nature as a blankness. Yet this Brooklyn vacant lot is teeming with life. House sparrows feed in a stand of horseweed, daisy fleabane, and curly dock.

BRANDON KEIM

imported by gardeners. Yet they have their own sort of nativity. They belong to a community of plants lately recognized by ecologists as characteristic of urban areas. They are, in the argot, ruderals. Disturbance specialists, wasteland-growers, found in abandoned spaces across New York City and much of the eastern United States.

These plants "live fast and die young," said Steven Handel, an ecologist at Rutgers University. They are annuals and short-lived perennials, able to flower and fruit and make seeds quickly, before someone cuts them or builds over them. Most have seeds lofted and dispersed by the wind. "Think of Brooklyn as an ocean of asphalt, with little archipelago islands of vegetation," Handel said. Some are dropped by birds, or carried in the fur of small mammals—mice and rats and feral cats—or on the shoes of local primates.

Moreover, these plants thrive in urban conditions, which are extreme. Like most large cities, New York City is a heat island, asphalt- and rooftop-trapped heat raising summer temperatures by an average of 5 degrees Fahrenheit. Vacant lot soil can be nutrient-poor and root-stuntingly compacted; at some point in the recent past, a building stood where Anzelone and I do. It's also dry, receiving relatively little precipitation from rainfall that evaporates or flows into sewers rather than collecting as groundwater.

Out of this, ruderals spring. With each passing year, their growth and eventual decomposition enrich and soften the earth, fixing nutrients and enlivening the soil. In the process they sequester carbon and clean the air. They cool surrounding air, too, and help capture rainfall that otherwise swamps New York City's overloaded sewers. Those are ecosystem services,

WALK THE LINE The Rockaway Rail Line, abandoned long ago, stretches beneath black cherry and white mulberry trees in Queens. Its wildness may soon be tamed, as plans are afoot to turn the railway into a park.

BRANDON KEIM

performed efficiently and free of charge, though that's just one perspective. Vacant lots serve others, too, creating food and habitat for the few creatures that live in the urban matrix, outside the protection of parks and conservation lands.

Anzelone and I sat for a while by a bumblebee-frequented patch of white clover. Something that's little-appreciated, she said, is how vacant lots provide pollinators with food throughout the growing season: dandelions in spring, followed by clovers, then asters and goldenrod that bloom until first frost. Urban gardeners rely on pollinators, but it's not gardens that sustain them. It's places like this. Handel estimates that, in a decent-sized New York City lot, some 500 insect species can be found.

I caught the electric green flash of a virescent sweat bee. Under a plantain leaf was a sow bug. Anzelone noticed a syrphid fly, part of an order that looks like bees. A black-and-yellow swallowtail butterfly flew overhead. House sparrows landed on power lines and foraged in a fallen *Ailanthus altissima*, or Tree of Heaven. In the suburbs, house sparrows are considered a songbird-threatening nuisance. To me they're musical neighbors. In my neighborhood I've also watched mockingbirds challenge crows, listened to cardinals sing their territorial bounds, thrilled to the blue-streaked flash of a kestrel falcon. They hunt the sparrows.

The vacant lot struck me as something like ecological graffiti. Not a cause of degradation, but a response to it. Mostly homogeneous in style, yet still a vibrant affirmation of life, and in some places beautiful, even special.

ACROSS THE RIVER in Manhattan, where the pace and density of development rarely allows empty places to flourish, there are few vacant lots. Until recently, though, there was one immense and particularly notable vacancy: a mile-long, 30-foot-wide stretch of elevated railroad track called the High Line, built in the 1930s, to haul freight down Manhattan's lower west side.

Soaring above meatpacking plants and warehouses, the High Line ceased operation in 1980, its last train delivering three carloads of frozen turkeys. The entrances were fenced off and locked up. The track itself, with only its steel-beam underbelly visible from street level, was largely forgotten, going quietly feral as the neighborhoods gentrified.

Now the warehouses are galleries, boutiques, and upscale lofts, and the High Line is an oasis of elegantly modernist paths lined with lush plantings conceived by world-renowned garden designer Piet Oudolf. There are some 210 species of flowers and shrubs and grasses, the names alone a litany of vegetative delight: rosemary willow and northern blazing star, twilight aster and white turtlehead.

This new High Line is widely celebrated as a visionary example of green urban design, the triumphant reclamation of disused space. Not much of what was reclaimed now is recalled; mostly it's remembered as an eyesore. There's but one formal record of what lived in the decades between its uses as railway and park, a study published in 2004 in the *Journal of the Torrey Botanical Society* by a St. John's University biologist named Richard Stalter.

"The elevated railroad is a relatively inaccessible 'island' and my access to the High Line was through an artists' loft to the roof of an adjoining building. There, a ladder and rope provided a 'bridge,' " wrote Stalter. When he arrived, Stalter didn't see a wasteland. Through his eyes, the tires and bottles and trash helped create "a multiplicity of habitats" in what was an example of ecological processes also found along roadsides and, more to the point, bare rock and newly formed islands.

On the High Line, as on volcanic promontories rising from the sea, wrote Stalter, lichens and moss had taken a tenacious hold on stone and steel, growing and dying and thereby creating a first skein of organic matter. Eventually enough gathered for a few wind-blown grass seeds to take root, adding their own trace deposits to the nascent soil. Abetted by wind-blown dust, it soon could support even larger plants. By the time Stalter arrived, a layer of soil covered the High Line in depths ranging to nearly three feet.

> Nearly all of what lives there is what someone has chosen. Nature's spontaneity, testament to life outside human control, is gone.

And what grew in that soil! Stalter documented no fewer than 161 species of lichens and plants, split between two zones: a small area of shrubs and low-growing trees, and a larger area of grasses and flowers. These included many species found in the Bedford Avenue vacant lot—but unlike that and most other lots, the High Line was never mowed to keep vegetation in check, and perhaps for that reason accumulated many more.

Among these were nine species of aster and goldenrod, and also lesser-known plants like joe-pye weed. Art Shapiro, a former Staten Island resident who's now an entomologist at the University of California, Davis (UC Davis), described it as "a short, shining moment" when the High Line was "an absolute butterfly heaven." Stalter didn't inventory the invertebrates, but he did compare the floral diversity to other sites around New York City. Altogether, he wrote, it appeared to possess "one of the highest levels of species richness of any temperate zone urban environment in the region."

If the old High Line was a disused eyesore, it was also a botanical cornucopia, and all the more remarkable because it was untended. Nobody watered it, or added soil or fertilizer. Nobody weeded it. What's there now is a fundamentally different type of nature than before: a garden, and in a sense far less sustainable, requiring careful tending and more water than is naturally available.

It's also brought pleasure to millions of visitors, helped popularize a vibrant, less-manicured gardening

It took a moment for the absurdity to sink in. Someone was planting trees in a forest.

aesthetic, and is far more pleasant than whatever would have been built had the High Line, spanning what's now some of the world's most expensive real estate, been torn down. There is joe-pye weed, and plenty of bees and butterflies, and birds, too. A few years ago, visitors watched peregrine falcons swoop down from their nest on the local Drug Enforcement Administration offices, which abut the High Line on 17th Street.

Yet when I walk the paths, something is missing. It's aesthetically pleasing but not inspiring. Nearly all of what lives there is what someone has chosen. Nature's spontaneity, testament to life outside human control, is largely gone. Of course people will argue that humans are part of nature, too, which is true; but there are different ways of being in nature. On the High Line, it's too easy to forget that verdancy is not the result of careful management, but life's inexorable course, present wherever we don't suffocate it.

"On a planet increasingly permeated with human intentionality, areas we allow to be there for themselves, that we allow to become what they will, can stand in contrast to human hubris," wrote Roger Kaye in an essay for the National Parks Service. "They can counter the dominating presumption that everything exists in relation to us."

Kaye, a wilderness specialist and pilot for the United States Fish and Wildlife Service in Alaska, likely had a very different setting in mind. The principle still applies, though, in the city. Marvelous as the High Line is, it exists in relation to us. It's no longer wild.

ABOUT 10 MILES SOUTHEAST of Manhattan, as the pigeon flies, a ribbon of defunct railway echoes the High Line before the landscape architects moved in. It's part of the Rockaway Rail Line, running 3.5 miles through Queens and Brooklyn. The last train rolled in 1962; the rails were fenced off from the public, and nature left to go feral. Now it's described as a blighted eyesore, a neglected ruin. It's also a place to know better.

On a hot June day, unable to find a way up that didn't involve climbing a utility pole, I walked the elevated southern section at street level. Over its concrete edges poked red cedar and black cherry trees, multiflora rose, the brown seedheads of pigweed. Seeing me take photographs, a man in a sleeveless T-shirt with a faded cross tattooed on his shoulder introduced himself. "It's like a wildlife preserve up there!" he said, home to raccoons and possums and a great many birds. The latter were his favorites. Early in the morning, when he left for work at a plumbing supply store, cardinals and lately bluebirds were out singing.

That elevated section, said Handel, the Rutgers ecologist, resembles the old High Line: life filling and slowly softening an expanse of rock and metal. The northern section is also like the High Line in its feral nature, though topographically quite different. With richer conditions to start from, it's now a forest, old enough for trees to wrap trunks around the rails. Undergrowth is dense, in many places nearly impenetrable, but in a few spots at least it's possible to access on foot.

On another day, I visited with Anzelone, the New York City botanist. She characterized the denseness as a mix of woodland natives and non-natives, many considered invasive. There were black cherry and white mulberry trees, horse chestnuts and pin oak and sassafras. Coiling some of the trunks and canopy were oriental bittersweet vines. There was Virginia creeper, and beds of poison ivy: a nuisance to humans, but manna for animals, who feed through winter on its fat-rich berries. Filling the understory were raspberry and porcelain berry bushes, nightshade and buckthorn: more manna.

Swallowtails flittered through openings in the canopy. A catbird thrashed in the brush, and a female cardinal perched nearby as we came upon several small trees in white plastic buckets. Tags identified them as part of the Million Trees Initiative, New York City's effort to expand urban tree cover. It took a moment for the absurdity to sink in, the implicit invisibility of the lushness around us. Someone was planting trees in a forest.

A local community group, Friends of the Queensway, hopes to turn the Rockaway Rail Line into a park called the Queensway. It would feature bicycle paths and gardens and meeting spaces; it would, argue the Friends, create jobs, improve public health, and simply be a fun place to go. Artistic renderings of the park look lovely. I'd be happy to have it in my neighborhood.

At the same time, I feel regret for what will happen should the railway become a park. Most of the verdancy will go. Trees will be beaten back, the poison ivy and bittersweet vines torn out, soil and water imported. Nobody, I suspect, will spare much thought for the birds.

Many scientists who consider these places from an ecological perspective see them as scrap heaps, dominated by invasive species that produce diminished, homogeneous ecosystems. The plants and animals living there don't need to be counted, and thinking otherwise risks a certain ecological Stockholm syndrome. After all, one could also celebrate the ruderal possibilities of a mine-tailing pond, or the parking lot borders of proposed developments in lush, ecologically rare Staten Island wetland forests.

Yet the Rockaway Rail Line, like the city's vacant lots, is to my eyes a treasure. Shapiro, the UC Davis entomologist, told me he saw vacant lots as "founts of evolutionary and ecological creativity" for dense urbanity, a space where megacity nature adjusts to our industrial presence, evolving the future's resilient ecosystems. To me they're simply rich, a place where nature's chorus refreshes the soul and you can feel a vital pulse of wildness. They're already homes, too. Life pushes back in vacant lots, asserting membership in a community of which, as Aldo Leopold put it, *Homo sapiens* is not a conqueror but "a plain member and citizen."

What it means to be a good neighbor to these communities, respectful and sharing, is a koan for the Anthropocene age. Ultimately it's our communities who decide what happens in their backyards. Confronted with a vacant lot, most people will prefer parks and gardens—somewhere to grow food and enjoy a neatly tended nature, one that's also not fenced off and gathering trash.

But these might be imagined from the perspective of vacant lot life, even inspired by it. As we think about developing our vacancies, we can get to know them: enjoy their plants and animals, challenge ourselves to plan in ways that support as much life as now exists. What we mow out of habit rather than need can be left to grow free. A few places might even be protected—pocket wilderness parks, with trails and benches, to go with our gardens. Maybe some of that Rockaway rail line poison ivy can be left for the birds.

Since visiting that Williamsburg lot with Anzelone, I've made my city sojourns with an eye to ruderals and the untended. There's far more life than I ever realized, and our own landscaping often suffers from the comparison. On one neglected side of a street, untended green will overflow, buzzing and blooming; on the other, a few desultory shrubs and factory-grown flowers stand in deserts of mulch and inch-high grass.

Recently I went back to Williamsburg, curious to see the lot in late summer. It's now a hole in the ground, with construction starting on an apartment building. It was difficult to begrudge. People need homes, and construction jobs. Later that day, I stopped by a vacant lot in my neighborhood. Until recently, it was a glorious profusion of Queen Anne's lace and chicory and milkweed, food for monarch butterflies that pass through New York City on their migration to Mexico.

Now it's mowed flat. There didn't seem to be any construction. Maybe someone complained to the Department of Sanitation, the city's vacant lot-mowers, about the unkempt growth. It's not unkempt now. It's obliterated. Shorn, silent and motionless, it's something close to nothing. Yet amid the stubble were stalks of fallen milkweed. Their pods were bursting with seed.

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GENIUS SEEMS TO BE a concept in decline. The MacArthur Foundation, which awards fellowships famously known as "genius grants," won't mention the word because, in its own words, "[genius] connotes a singular character of intellectual prowess [whereas] the people we seek to support express many other important qualities." The Google n-gram for genius shows a steady decline in its use over the past 200 years. Academics regularly proclaim it as dead.

At the same time, there is a burgeoning industry selling the message that there is genius in each of us—and we're buying. Amazon lists about 200 books and baubles concerning "inner genius," gurus like Laura Garnett give TED lectures about "Your Zone of Genius," and we debate whether 10,000 hours is indeed enough to make us exceptionally good in any field. For an idea on its way out, genius is staging a strong final act.

Which is not surprising. It is a powerful concept, drawing a dotted line around that which is best in us. But what, exactly, is best in us, and how should we react if we find it, not just in individual people, but in crowds, animals, and machines?

Welcome to "Genius."

—MS

"If we consider the idea of "genius" as it has evolved across history, it starts to look like we don't really need geniuses as we once did. It may be that we don't need them at all."

DARRIN M. MCMAHON
"From Isaac Newton to the Genius Bar" p. 146

Genius

OFF THE PEDESTAL

Super-Intelligent Humans Are Coming

Genetic engineering will one day create the smartest humans who have ever lived

BY STEPHEN HSU

"I always thought von Neumann's brain indicated that he was from another species, an evolution beyond man."
—Nobel Laureate Hans A. Bethe

"Alpha children wear grey. They work much harder than we do, because they're so frightfully clever. I'm really awfully glad I'm a Beta, because I don't work so hard. And then we are much better than the Gammas and Deltas. Gammas are stupid."
—Aldous Huxley, *Brave New World*

LEV LANDAU, A NOBELIST and one of the fathers of a great school of Soviet physics, had a logarithmic scale for ranking theorists, from 1 to 5. A physicist in the first class had 10 times the impact of someone in the second class, and so on. He modestly ranked himself as 2.5 until late in life, when he became a 2. In the first class were Heisenberg, Bohr, and Dirac among a few others. Einstein was a 0.5!

My friends in the humanities, or other areas of science like biology, are astonished and disturbed that physicists and mathematicians (substitute the polymathic von Neumann for Einstein) might think in this essentially hierarchical way. Apparently, differences in ability are not manifested so clearly in those fields. But I find Landau's scheme appropriate: There are many physicists whose contributions I cannot imagine having made.

I have even come to believe that Landau's scale could, in principle, be extended well below Einstein's 0.5. The genetic study of cognitive ability suggests that there exist today variations in human DNA which, if combined in an ideal fashion, could lead to individuals with intelligence that is qualitatively higher than has ever existed on Earth: Crudely speaking, IQs of order 1,000, if the scale were to continue to have meaning.

ILLUSTRATION BY GEMMA O'BRIEN

In Daniel Keyes' novel *Flowers for Algernon*, a mentally challenged adult called Charlie Gordon receives an experimental treatment to raise his IQ from 60 to somewhere in the neighborhood of 200. He is transformed from a bakery worker who is taken advantage of by his friends, to a genius with an effortless perception of the world's hidden connections. "I'm living at a peak of clarity and beauty I never knew existed," Charlie writes. "There is no greater joy than the burst of solution to a problem ... This is beauty, love, and truth all rolled into one. This is joy." The contrast between a super-intelligence and today's average IQ of 100 would be greater still.

The possibility of super-intelligence follows directly from the genetic basis of intelligence. Characteristics like height and cognitive ability are controlled by thousands of genes, each of small effect. A rough lower bound on the number of common genetic variants affecting each trait can be deduced from the positive or negative effect on the trait (measured in inches of height or IQ points) of already discovered gene variants, called alleles.

The Social Science Genome Association Consortium, an international collaboration involving dozens of university labs, has identified a handful of regions of human DNA that affect cognitive ability. They have shown that a handful of single-nucleotide polymorphisms in human DNA are statistically correlated with intelligence, even after correction for multiple testing of 1 million independent DNA regions, in a sample of over 100,000 individuals.

If only a small number of genes controlled cognition, then each of the gene variants should have altered IQ by a large chunk—about 15 points of variation between two individuals. But the largest effect size researchers have been able to detect thus far is less than a single point of IQ. Larger effect sizes would have been much easier to detect, but have not been seen.

This means that there must be at least thousands of IQ alleles to account for the actual variation seen in the general population. A more sophisticated analysis (with large error bars) yields an estimate of perhaps 10,000 in total.[1]

Each genetic variant slightly increases or decreases cognitive ability. Because it is determined by many small additive effects, cognitive ability is normally distributed, following the familiar bell-shaped curve, with more people in the middle than in the tails. A person with more than the average number of positive (IQ-increasing) variants will be above average in ability. The number of positive alleles above the population average required to raise the trait value by a standard deviation—that is, 15 points—is proportional to the square root of the number of variants, or about 100. In a nutshell, 100 or so

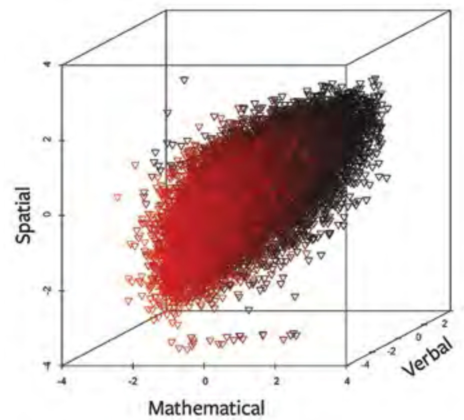
THE OVERNIGHT GENIUS Actor Cliff Robertson, who plays the part of bakery worker-turned-genius Charly (spelled Charlie in the novel), studies an illustration of a maze in this scene from the 1967 film adaptation of *Flowers for Algernon.*

PHOTO BY CINERAMA/COURTESY OF GETTY IMAGES additional positive variants could raise IQ by 15 points.

Given that there are many thousands of potential positive variants, the implication is clear: If a human being could be engineered to have the positive version of each causal variant, they might exhibit cognitive ability which is roughly 100 standard deviations above average. This corresponds to more than 1,000 IQ points.

It is not at all clear that IQ scores have any meaning in this range. However, we can be confident that, whatever it means, ability of this kind would far exceed the maximum ability among the approximately 100 billion total individuals who have ever lived. We can imagine savant-like capabilities that, in a maximal type, might be present all at once: nearly perfect recall of images and language; super-fast thinking and calculation; powerful geometric visualization, even in higher dimensions; the ability to execute multiple analyses or trains of thought in parallel at the same time; the list goes on. Charlie Gordon, squared.

To achieve this maximal type would require direct editing of the human genome, ensuring the favorable genetic variant at each of 10,000 loci. Optimistically, this might someday be possible with gene editing technologies similar to the recently discovered CRISPR/Cas system that has led to a revolution in genetic engineering in just the past year or two. Harvard genomicist George Church has even suggested that CRISPR will allow the resurrection of mammoths through the selective editing of Asian elephant embryo genomes. Assuming Church is right, we should add super-geniuses to mammoths on the list of wonders to be produced in the new genomic age.



SMART IS SMART The Project Talent study looked at the mathematical, verbal, and spatial skills of over 100,000 ninth-graders, as displayed in this scatterplot. Ability in one area was positively correlated with ability in the other two.

SOME OF THE ASSUMPTIONS behind the prediction of 1,000 IQs are the subject of ongoing debate. In some quarters, the very idea of a quantification of intelligence is contentious.

In his autobiographical book *Surely You're Joking, Mr. Feynman!*, the Nobel Prize-winning physicist Richard Feynman dedicated an entire chapter to his quest to avoid the humanities, called "Always Trying to Escape." As a student at the Massachusetts Institute of Technology, he says, "I was interested only in science; I was not good at anything else."

The sentiment is a familiar one: Common wisdom sometimes says that people who are good at math are not so good with words, and vice versa. This distinction has affected how we understand genius, suggesting it is an endowment of one particular faculty of the brain, and not a general superlative of the whole brain itself. This in turn makes the idea of apples-to-apples comparisons of intelligence moot, and the very idea of a 1,000 IQ problematic.

But psychometric studies, which seek to measure the nature of intelligence, paint a different picture. Millions of observations have shown that essentially all "primitive" cognitive abilities—short and long term memory, the use of language, the use of quantities and numbers, the visualization of geometric relationships, pattern recognition, and so on—are positively correlated. The figure "Smart Is Smart," above, displays graphically the ability scores of a large group of individuals, in areas such as mathematical, verbal, and spatial performance. The space of the graph is not filled uniformly, but instead the points cluster along an ellipsoidal region with a single long (or principal) axis.

These positive correlations between narrow abilities suggest that an individual who is above average in one area (for example, mathematical ability) is more likely to be above average in another (verbal ability). They also suggest a robust and useful method for

The Flynn Effect

The Flynn effect, named after the philosopher James Flynn, refers to a significant increase in raw cognitive scores over the last 100 years or so—the equivalent of two standard deviations in some cases. This raises a number of thorny issues. Were our ancestors idiots? Is cognitive ability really so malleable under environmental influence (contrary to what has been found in recent twin studies)?

The average person 100 years ago was massively deprived by today's standards—much more so than we would ever be allowed to reproduce in a modern twin study. United States gross domestic product per capita is eight times higher now, and the average number of years people spend in school has increased dramatically. In the America of 1900, adults had an average of about seven years of schooling, a median of 6.5 years, and 25 percent had completed four years or less. Modern twin and adoption studies only include individuals raised in a much smaller range of environments—almost all participants in recent studies have had legally mandated educations, which in the U.S. includes at least several years of high school.

There is a revealing analogy with height. While taller parents tend to have taller children (i.e., height is heritable), significant gains in average height which mirror the Flynn effect (amounting to an almost +2 standard deviation change) have been observed as nutrition and diet have improved.

compressing information concerning cognitive abilities. By projecting the performance of an individual onto the principal axis, we can arrive at a single number measure of cognitive ability results: the general factor g. Well-formulated IQ tests are estimators of g.

Does g predict genius? Consider the Study of Mathematically Precocious Youth, a longitudinal study of gifted children identified by testing (using the SAT, which is highly correlated with g) before age 13. All participants were in the top percentile of ability, but the top quintile of that group was at the one in 10,000 level or higher. When surveyed in middle age, it was found that even within this group of gifted individuals, the probability of achievement increased drastically with early test scores. For example, the top quintile group was six times as likely to have been awarded a patent than the lowest quintile. Probability of a STEM doctorate was 18 times larger, and probability of STEM tenure at a top-50 research university was almost eight times larger. It is reasonable to conclude that g represents a meaningful single-number measure of intelligence, allowing for crude but useful apples-to-apples comparisons.

Another assumption behind the 1,000-IQ prediction is that cognitive ability is strongly affected by

SUPERSIZE ME The breeding of domesticated plants and animals has changed some populations by as much as 30 standard deviations. Broiler chickens, for example, have increased in size more than four times since 1957. A similar approach could be applied to human intelligence, leading to IQs greater than 1,000.

1957–905g 1978–1,808g 2005–4,202g

genetics, and that g is heritable. The evidence for this assumption is quite strong. In fact, behavior geneticist and twins researcher Robert Plomin has argued that "the case for substantial genetic influence on g is stronger than for any other human characteristic."[2]

In twin and adoption studies, pairwise IQ correlations are roughly proportional to the degree of kinship, defined as the fraction of genes shared between the two individuals. Only small differences due to family environment were found: Biologically unrelated siblings raised in the same family have almost zero correlation in cognitive ability. These results are consistent over large studies conducted in a variety of locations, including different countries.

In the absence of deprivation, it would seem that genetic effects determine the upper limit to cognitive ability. However, in studies where subjects have experienced a wider range of environmental conditions, such as poverty, malnutrition, or lack of education, heritability estimates can be much smaller. When environmental conditions are unfavorable, individuals do not achieve their full potential (see The Flynn Effect on page 144).

SUPER-INTELLIGENCE MAY BE A distant prospect, but smaller, still-profound developments are likely in the immediate future. Large data sets of human genomes and their corresponding phenotypes (which are the physical and mental characteristics of the individual) will lead to significant progress in our ability to understand the genetic code—in particular, to predict cognitive ability. Detailed calculations suggest that millions of phenotype-genotype pairs will be required to tease out the genetic architecture, using advanced statistical algorithms. However, given the rapidly falling cost of genotyping, this is likely to happen in the next 10 years or so. If existing heritability estimates are any guide, the accuracy of genomic-based prediction of intelligence could be better than about half a population standard deviation (meaning better than plus or minus 10 IQ points).

Once predictive models are available, they can be used in reproductive applications, ranging from embryo selection (choosing which IVF zygote to implant) to active genetic editing (for example, using CRISPR techniques). In the former case, parents choosing between 10 or so zygotes could improve the IQ of their child by 15 or more IQ points. This might mean the difference between a child who struggles in school, and one who is able to complete a good college degree. Zygote genotyping from single cell extraction is already technically well developed, so the last remaining capability required for embryo selection is complex phenotype prediction. The cost of these procedures would be less than tuition at many private kindergartens, and of course the consequences will extend over a lifetime and beyond.

The corresponding ethical issues are complex and deserve serious attention in what may be a relatively short interval before these capabilities become a reality. Each society will decide for itself where to draw the line on human genetic engineering, but we can expect a diversity of perspectives. Almost certainly, some countries will allow genetic engineering, thereby opening the door for global elites who can afford to travel for access to reproductive technology. As with most technologies, the rich and powerful will be the first beneficiaries. Eventually, though, I believe many countries will not only legalize human genetic engineering, but even make it a (voluntary) part of their national healthcare systems.

The alternative would be inequality of a kind never before experienced in human history.

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PRIDE
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From Isaac Newton to the Genius Bar

Why it's time to retire the concept of genius

BY DARRIN M. MCMAHON

GENIUSES ARE A DYING BREED. And yet, they seem to be all around us. We live at a time when commentators speak without irony of "ordinary genius" and claim to find it everywhere. From the "genius bar" at the local Apple Store to bestselling books that trumpet "the genius in all of us," geniuses seem to abound. But if we consider the idea of "genius" as it has evolved across history, it starts to look like we don't really need geniuses as we once did. It may be that we don't need them at all. The increasing banality of genius in the contemporary world has begun to dissolve it as a useful category.

The modern genius emerged in 18th-century Europe as the focal point of a secular devotion of the sort previously reserved for saints. Like the prophets of old, these geniuses were conceived as higher beings endowed with natural gifts—intelligence, creativity, and insight took the place of grace. They, too, were granted a privileged place in the order of creation. As one astounded contemporary asked of Isaac Newton, among the first exemplars of the modern genius, "Does he eat, drink, and sleep like other men?" His virtues, commented another, "proved him a Saint [whose] discoveries might well pass for miracles." Newton had revealed the laws of the universe—had he not?—and seen into the mind of God.

Just like their saintly predecessors, the bodies of "geniuses" were treated as holy relics. Upon his death in 1727, Newton was buried in Westminster Abbey, resting place of the saints, and though his skull and bones were left intact (contemporaries marveled instead at his tomb, his death mask, and the many items he had owned and touched), the remains of other geniuses were picked over and venerated as the relics of the special dead. Three of Galileo's fingers were detached when his body was exhumed in 1737; Voltaire's heart and brain were absconded with at his death in 1778. Admirers fashioned rings from the repatriated bones of René Descartes during the French Revolution, and

ILLUSTRATION BY ROSE WONG

the skull of the great German poet Schiller was housed in a special shrine in the library of the Duke of Weimar in the early 19th century.

In the decades that followed, bits and pieces of genius were trafficked and traded across Europe: the skulls of Haydn and Goya, the heart of Percy Bysshe Shelley, shards of Beethoven's skull, locks of Napoleon's hair. Even a bit of flesh purporting to be the latter's penis traded hands for good money. As the Austrian critic Edgar Zilsel observed in his 1918 study, fittingly entitled *Die Geniereligion* (the Genius Religion), "We worship the relics of our great men, their autographs and locks of hair, their quill pens and tobacco cases, like the Catholic Church worships the bones, implements, and robes of the saints." To behold a relic of genius was to search for the lingering trace of a force that had once animated the flesh and still beckoned beyond the profane. To those unable, or unwilling, to satisfy their yearning for the transcendent by other means, the cult of genius as it took shape in Europe provided an outlet for displaced religious longing.

Yet even as worshippers were gazing in sublime wonder at the *memento mori* of genius, scientists were beginning to seek the roots of genius in human physiology. Physiognomists and phrenologists sought to discern the singularity of superior minds in the folds of the face and the bumps of the skull. Physicians and psychologists looked for what they called genius' "stigmata," the outward signs of that rare inner force they confirmed by indicators such as neurosis, eccentricity, and mental disease, their work motivated by the scientific empiricism and rationality of the dawning age of Enlightenment. Moved by a desire to establish the natural and biological basis of human difference, this work began responding to the emergence of a contrasting claim—that all human beings are created equal.

The political and philosophical belief in human equality which rose to the fore in the same century that witnessed the birth of the modern genius, and in the context of the American and French Revolutions, raised a troubling question that many Enlightened scientists and statesmen tried to answer: If men and women were no longer to be ruled according to the hierarchies of blood and birth that had long divided the many from the few, how then should modern societies be arranged? Who was most fit to lead? Thomas Jefferson was far from alone when he hoped that a "natural aristocracy" based on "worth and genius" might emerge to replace the "artificial aristocracy" of wealth and birth. In the 19th century, "geniologists"—scientists who studied genius—played a critical role in the search to single out a new kind of natural-born elite. Pioneers in the application of modern statistical methods, such as Francis Galton, attempted to measure the distribution along the bell curve of what he called, in his 1869 magnum opus of that name, hereditary genius. By Galton's calculations, geniuses—those "grand human animals, of natures preeminently noble, born to be kings of men"—appeared statistically on the order of one in 10 million.

> Much of early genius science was predicated not only on the belief in the natural superiority of the few, but on the natural inferiority of the many.

Galton was not only a leading student of genius, but the father of eugenics, a connection that underscores the extent to which much of early genius science was predicated not only on the belief in the natural superiority of the few, but on the natural inferiority of the many. To insist on the genius' special election was to "protest" vehemently, as Galton put it, against "pretensions of natural equality." By highlighting the natural (and hereditary) endowments of grand human animals (animals who were invariably white European males of supposedly superior stock), thinkers such as Galton aimed to combat what they saw as potentially leveling influences of modern mass society by legitimating the rule of natural elites. Geniuses were needed in this reckoning to guarantee, as Galton's acolyte, the American psychologist Lewis Terman, put it in his 1925

DIGITAL HISTORY Three of Galileo's fingers and one of his teeth are displayed in reliquaries at the Museo Galileo in Italy.

JOANNA EBENSTEIN/MORBID ANATOMY

book, *Genetic Studies of Genius*, "a nation's resources of intellectual talent." Terman continued, "The origins of genius, [and] the natural laws of its development, are scientific problems of almost unequaled importance for human welfare."

A key architect in creating and instrumentalizing the IQ exam, Terman scoffed, like Galton and the great majority of genius scientists, at the religious implications of the genius cult. He set out to combat the "influence of current beliefs, partaking of the nature of superstitions, regarding the essential nature of the Great Man, who has commonly been regarded by the masses as qualitatively set off from the rest of mankind, the product of supernatural causes." And yet the irony is that by isolating the statistical outliers of genius on the extreme end of a bell curve, the work of scientists like Galton and Terman served to reaffirm those superstitions. Geniuses were set off qualitatively from the rest of humanity, prodigies of nature whose natural endowments allowed them to do wondrous things. Geniuses possessed powers that made them kings.

In the first half of the 20th century, the prospect of geniuses ruling in sovereignty over the masses enthralled regimes as varied as Soviet Russia and Nazi Germany. When Vladimir Lenin, the "genius of the revolution," died in 1924, Stalin invited elite brain scientists to Moscow to probe the "material substrate" of the genius' genius. As Leon Trotsky had declaimed the year before, "Lenin was a genius," and "a genius is born once in a century." The chance was not to be missed. In Nazi Germany, scientists made studies of their own, while joining in a widespread cult of genius that helped propel Adolf Hitler to power. Hitler's minister of propaganda, Joseph Goebbels, spoke for many Germans when he hailed the Fuhrer as a "genius," the "natural, creative instrument of divine fate."

This excessive and often perverse worship of political leaders as supermen or saints helped create conditions for the demise of the modern genius. In the aftermath of World War II, the worship of "Great Men" was rendered suspect, while associations with eugenics cast aspersion on much of the science of genius. Scientists themselves largely abandoned the term, reserving it for the notable exception of Einstein. Hailed as "the genius of geniuses" and as a "saint," Einstein was in many respects the last of an already-endangered species.

For it was more than just revulsion at the excesses of the genius cult and the science that propped it up that threatened the genius with extinction. Gradually, society shifted to bear out a prophecy made by that great 19th-century analyst of American democracy, Alexis de Tocqueville: Geniuses would become more rare as enlightenment became more common. Tocqueville believed that with the steady extension of education, equality, and opportunity to ever wider sectors of the population, what had once been concentrated in the exceptional few would slowly be "divided equally among all." To some degree Tocqueville felt this as a potential loss—he believed that modern democracies leveled and flattened, pulling down those who would strive to stand above the crowd. But rather than mourning the diminution of a certain sort of towering genius, he looked with anticipation toward the tremendous possibilities that might arise if a nation were to marshal more of its human potential. Tocqueville understood there could be immense strength in numbers—that many heads could be better than one.

Modern democratic societies have, to some degree, seen Tocqueville's prophecy come to pass. We now rightly detect genius in different colors, genders, and cultures, and we appreciate its manifestations beyond the realms of science, statecraft, and the high arts to which genius was classically confined. So too do we appreciate the creative potential of networks and the collective nature of creativity, invoked as the "genius of groups" or the "wisdom of crowds." We celebrate the power of collaboration evidenced in Silicon Valley or "idea factories" such as Bell Labs, which at its height employed close to 1,200 Ph.D.s, producing one stunning innovation after the next (along with 13 Nobel Prizes). We insist, more than ever, that creativity and talent—even genius—exist in a multiplicity of forms. Some scientists now speak of "emotional intelligence," and "multiple intelligences." Others, such as the psychologist Anders Erickson, have conducted studies that illustrate the critical role of "deliberate practice" and exposure in fostering expert achievement, denying that genius is in the genes. And still other scientists stress that even if certain aptitudes or abilities are largely innate, nature scatters its array of seeds widely. Even the pioneer of the general intelligence factor (g) and arch-hereditarian Charles Spearman was prepared to admit, "every normal man, woman, and child is ... a genius at something."

Such healthy pluralism can have its absurdities, of course, suggesting a world not unlike Garrison Keillor's Lake Wobegon, "where all children are above average," replete with "Baby Einsteins and Baby Mozarts." A thriving self-help literature purrs comfortingly about the hidden "genius within" and instructs readers *How to Be a Genius* and *How to Think Like Leonardo da Vinci*, providing *Seven Steps to Genius Every Day*. Apparently, there is genius in everyone now, at all times, and in all things. The title of a recently published sex-guide for women sums up the situation: *Penis Genius*.

This is the paradox of genius in our time: On the one hand, the world we inhabit is an inhospitable place for that creature first conceived in the 18th century as a human of sacred exception; on the other hand, we have created a new variety of the species, which threatens to overrun us all. The risk inherent in this situation is of obscuring genuine differences in aptitude, capacity, and ability, while at the same time becoming apologists for the real inequalities of opportunity and resources that might foster those differences. Recent data on the widening education achievement gap between rich and poor paints a troubling picture of a nation all too ready to squander its human potential. Despite our desire to "leave no child behind," we do so every day, which prompts the terrible question: How many children living among us have the potential for genius that we'll never know? As the late evolutionary biologist Stephen Jay Gould once observed, "I am, somehow, less interested in the weight and convolutions of Einstein's brain than in the near certainty that people of equal talent have lived and died in cotton fields and sweatshops."

Which is not to say that we should mourn the passing of the genius as first conceived in the 18th century. That creature has outlived its cultural usefulness, and perhaps it is time to say the same of the more recent varieties. By kicking the habit of genius, we might better be able to cultivate what is just as important and in the long run more essential to human civilization: the potential in all of us.

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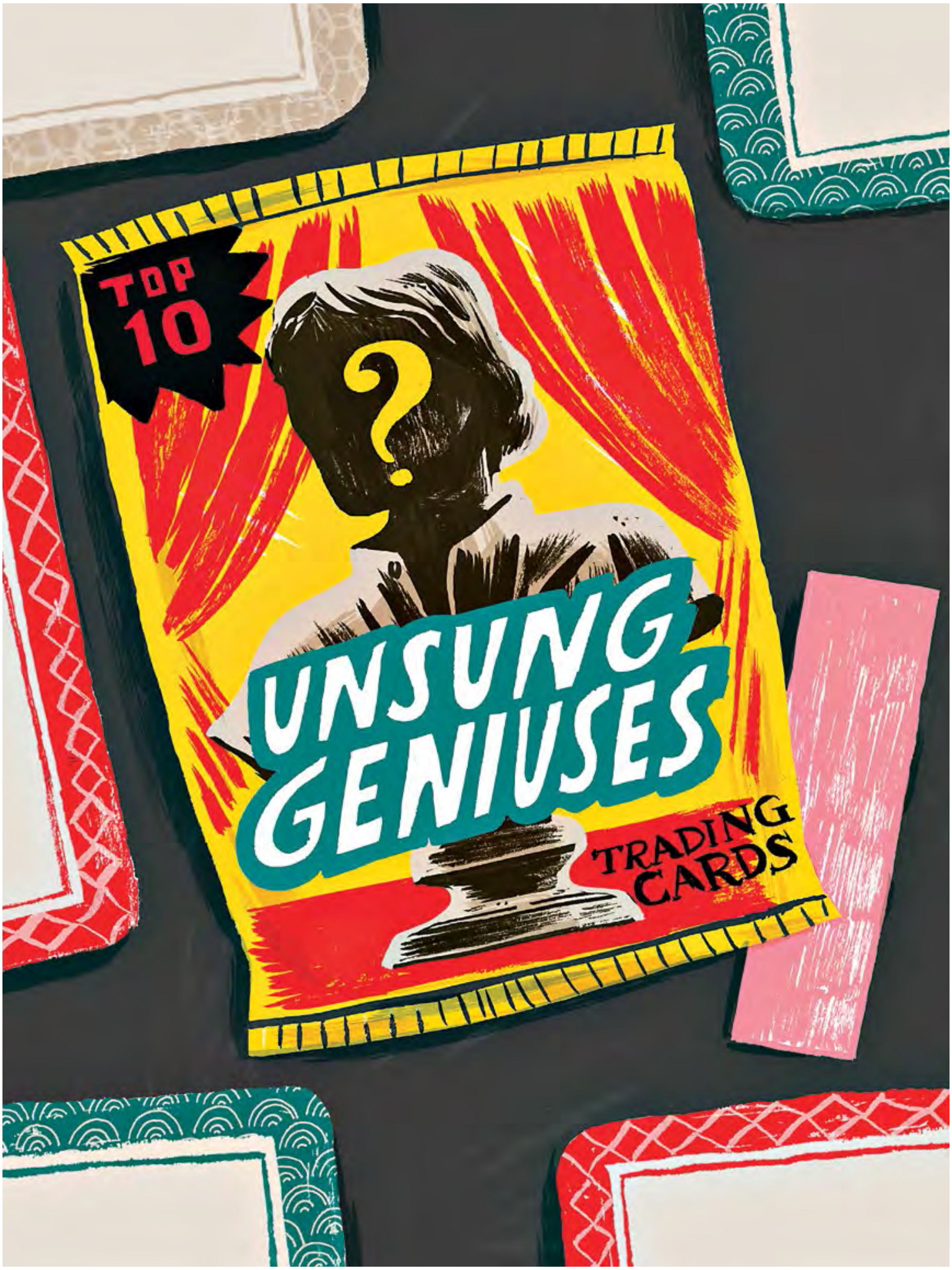


"TOP TEN UNSUNG GENIUSES"
ILLUSTRATION BY **MIKE REDDY**

Who Really Found the Higgs Boson

The real genius in the Nobel Prize-winning discovery is not who you think it is

BY NEAL HARTMAN

TO THOSE WHO SAY that there is no room for genius in modern science because everything has been discovered, Fabiola Gianotti has a sharp reply. "No, not at all," says the former spokesperson of the ATLAS Experiment, the largest particle detector at the Large Hadron Collider at CERN. "Until the fourth of July, 2012 we had no proof that nature allows for elementary scalar fields. So there is a lot of space for genius."

She is referring to the discovery of the Higgs boson two years ago—potentially one of the most important advances in physics in the past half century. It is a manifestation of the eponymous field that permeates all of space, and completes the standard model of physics: a sort of baseline description for the existence and behavior of essentially everything there is.

By any standards, it is an epochal, genius achievement.

What is less clear is who, exactly, the genius is. An obvious candidate is Peter Higgs, who postulated the Higgs boson, as a consequence of the Brout-Englert-Higgs mechanism, in 1964. He was awarded the Nobel Prize in 2013 along with Francois Englert (Englert and his deceased colleague Robert Brout arrived at the same result independently). But does this mean that Higgs was a genius? Peter Jenni, one of the founders and the first "spokesperson" of the ATLAS Experiment Collaboration (one of the two experiments at CERN that discovered the Higgs particle), hesitates when I ask him the question.

"They [Higgs, Brout, and Englert] didn't think they [were working] on something as grandiose as [Einstein's relativity]," he states cautiously. The spontaneous symmetry breaking leading to the Higgs "was a challenging question, but [Einstein] saw something new and solved a whole field. Peter Higgs would tell you, he worked a few weeks on this."

What, then, of the leaders of the experimental effort, those who directed billions of dollars in investment and thousands of physicists, engineers, and students

ILLUSTRATION BY OWEN FREEMAN

from almost 40 countries for over three decades? Surely there must have been a genius mastermind directing this legion of workers, someone we can single out for his or her extraordinary contribution.

"No," says Gianotti unequivocally, which is rare for a physicist, "it's completely different. The instruments we have built are so complex that inventiveness and creativity manifests itself in the day-by-day work. There are an enormous amount of problems that require genius and creativity to be spread over time and over many people, and all at the same level."

Scientific breakthroughs often seem to be driven by individual genius, but this perception belies the increasingly collaborative nature of modern science. Perhaps nothing captures this dichotomy better than the story of the Higgs discovery, which presents a stark contrast between the fame awarded to a few on the one hand, and the institutionalized anonymity of the experiments that made the discovery possible on the other.

AN AVERSION TO THE NOTION of exceptional individuals is deeply rooted within the ATLAS collaboration, a part of its DNA. Almost all decisions in the collaboration are approved by representative groups, such as the Institute Board, the Collaboration Board, and a plethora of committees and task forces. Consensus is the name of the game. Even the effective CEO, a role Gianotti occupied from 2009 to 2013, is named the "Spokesperson." She spoke for the collaboration, but did not command it.

Collectivity is crucial to ATLAS in part because it's important to avoid paying attention to star personalities, so that the masses of physicists in the collaboration each feel they own the research in some way. Almost 3,000 people qualify as authors on the key physics papers ATLAS produces, and the author list can take almost as many pages as the paper itself (see The Genius of Crowds).

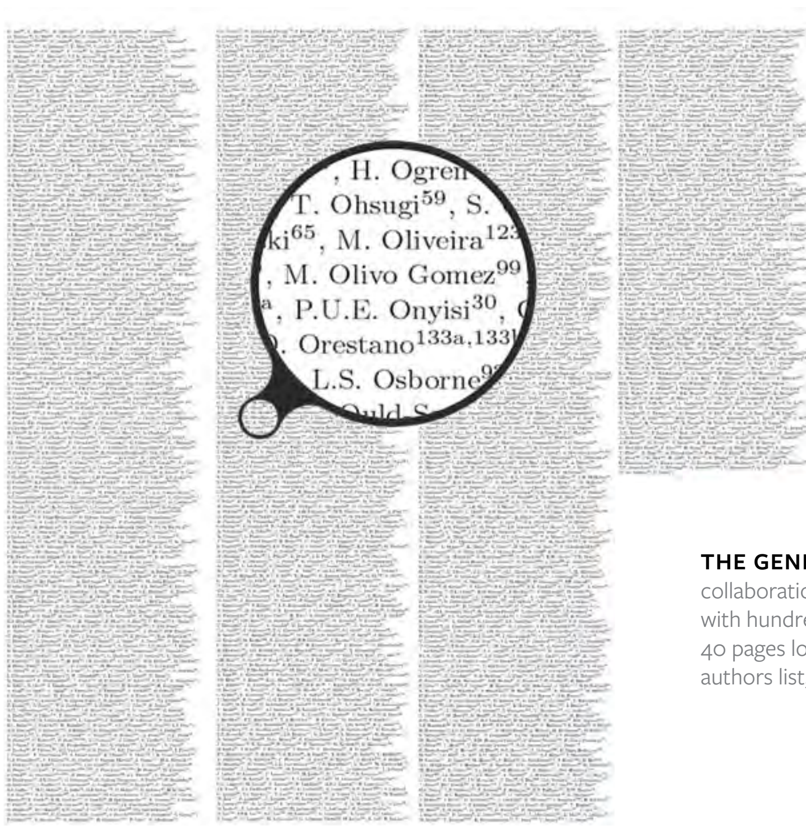
On a more functional level, this collectivity also makes it easier to guard against bias in interpreting the data. "Almost everything we do is meant to reduce potential bias in the analysis," asserts Kerstin Tackmann, a member of the Higgs to Gamma Gamma analysis group during the time of the Higgs discovery, and recent recipient of the Young Scientist Prize in Particle Physics. Like many physicists, Tackmann verges on the shy, and speaks with many qualifications. But she becomes more forceful when conveying the importance of eliminating bias.

"We don't work with real data until the very last step," she explains. After the analysis tools—algorithms and software, essentially—are defined, they are applied to real data, a process known as the unblinding. "Once we look at the real data," says Tackmann, "we're not allowed to change the analysis anymore." To do so might inadvertently create bias, by tempting the physicists to tune their analysis tools toward what they hope to see, in the worst cases actually creating results that don't exist. The ability of the precocious individual physicist to suggest a new data cut or filter is restricted by this procedure: He or she wouldn't even see real data until late in the game, and every analysis is vetted independently by multiple other scientists.

> One famous member of the collaboration is looked upon dubiously by many, who see him as drawing too much attention to himself.

This collective discipline is one way that ATLAS tames the complexity of the data it produces, which in raw form is voluminous enough to fill a stack of DVDs that reaches from the earth to the moon and back again, 10 times every year. The data must be reconstructed into something that approximates an image of individual collisions in time and space, much like the processing required for raw output from a digital camera.

But the identification of particles from collisions has become astoundingly more complex since the days of "scanning girls" and bubble chamber negatives, where actual humans sat over enlarged images of collisions and identified the lines and spirals as different particles. Experimentalists today need to have expert knowledge of the internal functioning of the



THE GENIUS OF CROWDS Particle physics collaborations can produce academic papers with hundreds of authors. One 2010 paper was 40 pages long—with 10 pages devoted to the authors list, pictured here.[1]

different detector subsystems: pixel detector, silicon strip tracker, transition radiation tracker, muon system, and calorimeters, both hadronic and electromagnetic. Adjustments made to each subsystem's electronics, such as gain or threshold settings, might cause the absence or inclusion of what looks like real data but isn't. Understanding what might cause false or absent signals, and how they can be accounted for, is the most challenging and creative part of the process. "Some people are really clever and very good at this," says Tackmann.

The process isn't static, either. As time goes on, the detector changes from age and radiation damage. In the end the process of perfecting the detector's software is never-ending, and the human requirements are enormous: roughly 100 physicists were involved in the analysis of a single and relatively straightforward particle signature, the decay of the Higgs into two Gamma particles. The overall Higgs analysis was performed by a team of more than 600 physicists.

The depth and breadth of this effort transform the act of discovery into something anonymous and distributed—and this anonymity has been institutionalized in ATLAS culture. Marumi Kado, a young physicist with tousled hair and a quiet zen-like speech that borders on a whisper, was one of the conveners of the "combined analysis" group that was responsible for finally reaching the level of statistical significance required to confirm the Higgs discovery. But, typically for ATLAS, he downplays the importance of the statistical analysis—the last step—in light of the complexity of what came before. "The final analysis was actually quite simple," he says. "Most of the [success] lay in how you built the detector, how well you calibrated it, and how well it was designed from the very beginning. All of this took 25 years."

THE DEEPLY COLLABORATIVE WORK model within ATLAS meant that it wasn't enough for it to innovate in physics and engineering—it also needed to innovate its management style and corporate culture. Donald Marchand, a professor of strategy execution and information management at IMD Business School in Lausanne, describes ATLAS as following a collaborative mode of working that flies in the face of standard "waterfall"—or top down—management theory.

Marchand conducted a case study on ATLAS during the mid-2000s, finding that the ATLAS management led with little or no formal authority.[2] Most people in the collaboration work directly "for" someone who is in no way related to their home institute, which actually writes their paycheck. For example, during the construction phase, the project leader of the ATLAS pixel detector, one of its most data-intensive components, worked for a United States laboratory in California. His direct subordinate, the project engineer, worked for an institute in Italy. Even though he was managing a critical role in the production process, the project leader had no power to promote, discipline, or even formally review the project engineer's performance. His only recourse was discussion, negotiation, and compromise. ATLAS members are more likely to feel that they work with someone, rather than for them.

Similarly, funding came from institutes in different countries through "memorandums of understanding" rather than formal contracts. The collaboration's spokesperson and other top managers were required to follow a politic of stewardship, looking after the collaboration rather than directing it. If collaboration members were alienated, that could mean the loss of the financial and human capital they were investing. Managers at all levels needed to find non-traditional ways to provide feedback, incentives, and discipline to their subordinates.

The coffee chat was one way to do this, and became the predominant way to conduct the little daily negotiations that kept the collaboration running. Today there are cafés stationed all around CERN, and they are full from morning to evening with people having informal meetings. Many physicists can be seen camped out in the cafeteria for hours at a time, working on their laptops between appointments. ATLAS management also created "a safe harbor, a culture within the organization that allows [employees] to express themselves and resolve conflicts and arguments without acrimony," Marchand says.

The result is a management structure that is remarkably effective and flexible. ATLAS managers consistently scored in the top 5 percent of a benchmark scale that measures how they control, disseminate, and capitalize on the information capital in their organization.[3] Marchand also found that the ATLAS management structure was effective at adapting to changing circumstances, temporarily switching to a more top-down paradigm during the core production phase of the experiment, when

MIND THE GAP Over 60 institutes collaborated to build and install a new detector layer inside a 9-millimeter gap between the beam pipe (the evacuated pipe inside of which protons circulate) and the original detector.

thousands of identical objects needed to be produced on assembly lines all over the world.

This collaborative culture didn't arise by chance; it was built into ATLAS from the beginning, according to Marchand. The original founders infused a collaborative ethic into every person that joined by eschewing personal credit, talking through conflicts face to face, and discussing almost everything in open meetings. But that ethic is codified nowhere; there is no written code of conduct. And yet it is embraced, almost religiously, by everyone that I spoke with.

Collaboration members are sceptical of attributing individual credit to anything. Every paper includes the entire author list, and all of ATLAS's outreach material is signed "The ATLAS Collaboration." People are suspicious of those that are perceived to take too much personal credit in the media. One famous member of the collaboration (as well as a former rock star and host of the highly successful BBC series, *Horizon*) is looked upon dubiously by many, who see him as drawing too much attention to himself through his association with the experiment.

IN SEARCHING FOR GENIUS at ATLAS, and other experiments at CERN, it seems almost impossible to point at anything other than the collaborations themselves. More than any individual, including the theorists who suggest new physics and the founders of experimental programs, it is the collaborations that reflect the hallmarks of genius: imagination, persistence, open-mindedness, and accomplishment.

The results speak for themselves: ATLAS has already reached its first key objective in just one-tenth of its projected lifetime, and continues to evolve in a highly collaborative way. This May, one of the first upgrades to the detector was installed. Called the Insertable B-Layer (IBL), it grew out of a task force formed near the end of ATLAS's initial commissioning period, in 2008, with the express goal of documenting why inserting another layer of detector into a 9-millimeter clearance space just next to the beam pipe was considered impossible.

Consummate opportunists, the task force members instead came up with a design that quickly turned into a new subproject. And though it's barely larger than a shoebox, the IBL's construction involved more than 60 institutes all over the world, because everyone wanted to be involved in this exciting new thing. When it came time to slide the Insertable B-layer sub-detector into its home in the heart of ATLAS earlier this year, with only a fraction of a millimeter of clearance over 7 meters in length, the task was accomplished in just two hours—without a hitch.

Fresh opportunities for new genius abound. Gianotti singles out dark matter as an example: "96 percent of the universe is dark. We don't know what it's made of and it doesn't interact with our instruments. We have no clue," she says. "So there is a lot of space for genius." But instead of coming from the wild-haired scientist holding a piece of chalk or tinkering in the laboratory, that genius may come from thousands of people working together.

NEAL HARTMAN is a mechanical engineer with Lawrence Berkeley Laboratory and has been working with the ATLAS collaboration at CERN for almost 15 years. He spends much of his time on outreach and education in both physics and general science, including running CineGlobe, a science-inspired film festival at CERN.

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Shakespeare’s Genius Is Nonsense

What the Bard can teach science about language and the limits of the human mind

BY JILLIAN HINCHLIFFE & SETH FREY

YOU'D BE FORGIVEN IF, settling into the fall 2003 "Literature of the 16th Century" course at the University of California, Berkeley, you found the unassuming 70-year-old man standing at the front of the lecture hall a bit eccentric. For one thing, the class syllabus, which was printed on the back of a rumpled flyer promoting bicycle safety, seemed to be preparing you for the fact that some readings may feel toilsome. "Don't worry," it read on the two weeks to be spent with a notoriously long allegorical poem; it's "only drudgery if you're reading it for school." *Phew!* you thought, then, *Wait a second…* You might have wondered what you had gotten yourself into. Then again, if you had enrolled in Stephen Booth's class, chances are that you already knew.

By this time, Booth had been teaching Shakespeare to Berkeley undergraduates for decades and had earned the adulation of thousands of students. A cynic might say that this was because he issued virtually no assignments. But that was because he wanted the work to be a labor of love. His goal was that students engage meaningfully with the readings rather than "going thoughtlessly, dutifully through institutionally approved motions" in search of a good grade.

Even if you'd taken a Shakespeare class from someone else, you'd be likely to encounter Booth. His prize-winning 1977 edition of Shakespeare's sonnets accompanies the 154 poems with over 400 pages of virtuosic commentary exploring the ambiguity and polysemy of Shakespeare's verse. It's nearly as dazzling an artifact as the sonnets themselves, an achievement so extraordinary that Booth has continued to win acclaim for decades, despite what some might see as his best efforts to distance himself from the inner circle of academia.

Although Booth is now retired, his work couldn't be more relevant. In the study of the human mind, old disciplinary boundaries have begun to dissolve and fruitful new relationships between the sciences and humanities have sprung up in their place. When it comes to the cognitive science of language, Booth may be the most prescient literary critic who ever put pen to paper. In his fieldwork in poetic experience, he unwittingly anticipated several language-processing phenomena that cognitive scientists have only recently begun to study. Booth's work not only provides one

ILLUSTRATION BY NEVER EVER EVEN

of the most original and penetrating looks into the nature of Shakespeare's genius, it has profound implications for understanding the processes that shape how we think.

UNTIL THE EARLY DECADES of the 20th century, Shakespeare criticism fell primarily into two areas: textual, which grapples with the numerous variants of published works in order to produce an edition as close as possible to the original, and biographical. Scholarship took a more political turn beginning in the 1960s, providing new perspectives from various strains of feminist, Marxist, structuralist, and queer theory. Booth is resolutely dismissive of most of these modes of study. What he cares about is poetics. Specifically, how poetic language operates on and in audiences of a literary work.

Close reading, the school that flourished mid-century and with which Booth's work is most nearly affiliated, has never gone completely out of style. But Booth's approach is even more minute—microscopic reading, according to fellow Shakespeare scholar Russ McDonald. And as the microscope opens up new worlds, so does Booth's critical lens. What makes him radically different from his predecessors is that he doesn't try to resolve or collapse his readings into any single interpretation. That people are so hung up on interpretation, on meaning, Booth maintains, is "no more than habit." Instead, he revels in the uncertainty caused by the myriad currents of phonetic, semantic, and ideational patterns at play.

What does that look like? Here's an example from *Antony and Cleopatra*, where one Roman describes to another the sight of Cleopatra's ships fleeing battle:

ENOBARBUS
How appears the fight?

SCARUS
On our side like the tokened pestilence
Where death is sure. Yon ribaudred nag of Egypt—
Whom leprosy o'ertake—i' th' midst o' th' fight,
When vantage like a pair of twins appeared,
Both as the same, or rather ours the elder,
The breese upon her, like a cow in June,
Hoists sails and flies.

Booth follows editorial convention in pointing out the two potential meanings of breese ("light wind" and "gadfly"). Meanwhile, he observes, the second, quieter effect of flies (denoting both "retreating" and "insects") has been passed over—but not without effect. While both senses of breese or flies pertain, Booth notes that "in calling the effect a pun, we both exaggerate and underestimate its effect"—exaggerate because it's less self-conscious than a pun, and underestimate because it achieves much more than one. An explicit pun is a momentary flash, and then it's over. More valuable for Booth are the links that spread out from each word based on "its sound, sounds that resemble it, its sense, its potential senses, their homonyms, their cognates, their synonyms, and their antonyms." Unexploded puns conserve their energy and preserve these links, creating rich, multilayered, imbricating patterns throughout a work.

What's essential to Booth is that for readers and audiences—for everyone but the professional critic—these patterns usually remain below the threshold of our attention. What he calls the "physics" of the verse are available to general readers, but not obtrusive. In his 1998 book *Precious Nonsense*, Booth argues that the experiences that Shakespeare's poetic language evokes with such verve and subtlety are intensifications of everyday language experiences. Shakespeare achieves this by weaving incredibly rich networks from the same kinds of "substantive nonsense and nonimporting patterns" that pop up in slang, jokes, songs, and nursery rhymes. Those dense networks of patterns, Booth posits, are "the principal source of the greatness we find in Shakespeare's work."

A COGNITIVE SCIENTIST LOOKING at Booth's explanation of Shakespearean effects would spot many concepts from her own discipline. Those include priming—when, after hearing a word, we tend more readily to recognize words that are related to it; expectation—the influence of higher-level reasoning on word recognition; and depth of processing—how varying levels of attention affect the extent of our engagement with a statement. (Shallow processing explains our predisposition to miss the problem of whether a man should be allowed to marry his widow's sister.)

The consonances are surprising, considering that when Booth established his method of criticism, the prevailing school of linguistics had no room for such ideas. Cognitive linguistics, a sympathetic approach that established the fundamental importance of metaphor in the structuring of human thought, didn't start to gain ground until the 1970s and '80s. Before that, the norm was generative linguistics, which deemed nonstandard speech acts aberrations unworthy of further scrutiny. This left lots of language unexplained: just think of the things that you read, hear, or say every day that, despite not adhering to the formal and logical rules of the language, you understand perfectly.

Cognitive linguistics offered a step forward in the sense that it embraces the complexity and ungrammaticality of everyday language. In earlier days, language processing was regarded as a black box: language goes in, comprehension comes out. More recently, dynamical cognitive linguists began to use tools from physics and calculus to get inside the black box, explaining shifting ambiguous meanings in terms of interacting equations. These mathematical tools allow dynamicists to emphasize that language interpretation happens in time, a point that Booth also emphasizes. What is so important about the actual moment-to-moment nature of reading? One clean illustration from cognitive science is in the conflict between the psychological processes of priming and expectation.

Our brains are structured such that if you hear an animal word (cat), it becomes easier to process another animal word (dog) when it's presented about half a second later. In the jargon, this is called priming: cat primes dog, and it happens quickly. Expectations describe a slower, more arbitrary type of connection. There is no fundamental relationship between animal words and office words. But if I put you in a psychology lab and present you with a series of animal words followed by office words (like desk), then you will learn an expectational relationship between them. Expectations take longer to kick in, about one to two seconds. So following cat with desk after only half a second won't help you process desk, but giving cat another second to sink in before presenting desk will link cat and desk as strongly as cat and dog.

Association and expectation are different processes occurring on different timescales, and they can interact in complex ways. Most strikingly, expectations can overpower associations. If you have come to expect an office word after an animal word, then cat will still prime dog after a half-second interval. But after a two-second interval, cat suppresses dog, making it harder to process. Authors who are sensitive to these effects, and careful about the linkages that they create, may be able to use the interactions of priming and expectation to create intricate experiences of time, language, and meaning.

Certain types of sentences are especially good at demonstrating the unfolding of meaning over time. Garden-path sentences ("The child rushed through the doorway fell") got their name because they lead their audiences into a syntactical dead end—down the garden path, so to speak. Although they've been remarked on for decades, they've been taken up more recently by dynamicists because they're especially useful for exploring questions of moment-to-moment language experience. Michael Spivey, professor of cognitive and information sciences at the University of California, Merced, and author of *The Continuity of Mind*, uses garden-path sentences to describe the unfolding of sentence understanding as a contest between every possible interpretation of that sentence, one in which revealing each subsequent word disqualifies more contenders until just one remains standing. What may first appear to be a statement about a running child ends up making more sense if it's about a child who, hurried across a threshold by his caretaker, loses his balance. Spivey's research shows that, until we arrive at a conclusion, we are capable of holding both meanings in mind simultaneously.

That people are so hung up on interpretation, on meaning, is no more than habit. Better to revel in uncertainty.

Booth claims that garden-path phenomena and similar ambiguities in Shakespeare's sonnets are essential to create in the reader the same unsettling mental states that they describe. His style of approaching these "substantially gratuitous journeys in the mind" aligns neatly with modern cognitive scientific approaches in that he not only tolerates but celebrates uncertainty. For Booth, the idea that readers manage continually shifting provisional interpretations—and that they don't notice themselves doing it—is an essential component of poetic richness. The sonnets are full of these "plays on momentary confusions." Take the following lines from Sonnet 79:

> I grant, sweet love, thy lovely argument
> Deserves the travail of a worthier pen

The first of these lines could be a complete sentence, using the vocabulary of debate invoked earlier in the poem to concede to the lover (or, adding another layer of uncertainty, to the speaker's own affection). While the next line "makes it clear that thy lovely argument means 'the theme of thy loveliness,' " Booth writes, "the process of reading this particular statement in this particular diction and syntax will have been such as to make the reader's state of mind as a reader similar to the speaker's state of mind as a lover. They have both experienced a sense that something is wrong."

> One scientist used EEG and other electrophysiological techniques to look at the effects of Shakespeare's verse on readers.

PHILIP DAVIS, PROFESSOR OF psychological sciences at the University of Liverpool and author of two books on Shakespeare and the brain, conducts research in reading and literary thinking. In one well-publicized study, Davis used EEG and other electrophysiological techniques to look at the moment-to-moment effects on readers of functional shifts in Shakespeare's verse.

Functional shifts occur when parts of speech are switched unexpectedly. They're a favorite Shakespearean device, but noun-to-verb conversions are especially common: Edgar's "He childed as I fathered" in *King Lear*, for example, or the hero's lament in *Antony and Cleopatra* about "The hearts that spanieled me at heels." According to Davis, the changes in EEG measurements between Shakespearean functional shifts and various control sentences demonstrate that "while the Shakespearean functional shift was semantically integrated with ease, it triggered a syntactic re-evaluation process likely to raise attention and extra emergent consciousness." In other words, the brain noticed something odd about the use of a noun as a verb, quickly made sense of it, and was put on high alert for more unusual activity.

To understand how we can accommodate to the shifting roles of nouns and verbs in real time, we need to appreciate the brain as constantly managing and integrating a deluge of information from many sources. Traditional approaches to language treated sounds, words, phrases, sentences, and meanings as essentially separable, and choked on language that relied on the multi-level interactions that characterize Shakespeare's verse. That our brains are continually bombarded by information from all sides, though, is a basic tenet of modern approaches to cognition. And, rather than overwhelming us with "information overload," this complexity can help us navigate the mess of real-world language. Researchers like Spivey argue that a heavier flow of information can actually smooth the activity of neural processes, much in the way that a circle, represented by infinite points, maps a smoother circuit than a hexagon, represented by only six.

Similarly, the integration of language over multiple mental systems—cognitive, perceptual, and sensory-motor—makes how we process it susceptible to even very subtle syntactic and semantic cues. Teenie Matlock, also at U.C. Merced, has demonstrated that the content of text can influence the act of reading it in surprisingly literal ways. Matlock's experiments with fictive motion—when we use motion verbs to describe things that cannot move, like "the road runs through the desert"—found that people read fictive motion sentences more slowly when they were preceded by sentences about difficult terrain ("The valley was bumpy and uneven") vs. easy ("The valley was flat and smooth"). This effect disappeared for sentences without fictive motion, as when the road was merely "in" the desert.

Booth seems once again to have an intuitive grasp of this relationship, not least because of the exuberant mobility with which he describes what Shakespeare does to us. It may look like we're sitting quietly in our chairs as we read a sonnet or watch one of the plays, he writes, but we're really making great leaps from one association to the next, performing "mental aerobatics." Yet it's in Booth's understanding of how specific verses propel or impede dramatic action that the connection between language and motion becomes most clear.

According to Booth, the greatest tragedy in *Macbeth* occurs in the audience, in the failure of moral categories that leaves us identifying with the title character despite his repugnant actions. He points out that later scenes repeatedly offer Malcolm to the audience as a potential way out, giving us several chances to switch our moral allegiance.

So why don't we? The answer, Booth says, is because Shakespeare doesn't want us to. To begin with, Malcolm's responses to the unfolding drama never seem quite appropriate. On learning that his father has been murdered, for example, he answers "O, by whom?"—"a response from which," Booth notes, "no amount of gasping and mimed horror can remove the tone of small talk."

By padding Malcolm's later speeches with an abundance of "syntactical stuffing," Shakespeare ensures that Malcolm comes off as plodding, bloviating, dramatically weak. "Malcolm's style is grating in its lack of economy," Booth explains; his "syntax is maddeningly contorted, and his pace tortuous ... no quantity of alternative adjectives and nouns can fill up the cistern of Malcolm's lust to dilate upon particulars."

Here, if ever, Shakespeare lays out bumpy verbal terrain. Even if we wanted to like Malcolm, the play encourages us not to simply because the way he speaks is so impedimentary. Malcolm slows things down. We never leave Macbeth; linguistically and otherwise, things are much more exciting when he's around.

"In the theatre, speed is good and slowness is bad," Booth writes. "In the story of Macbeth as staged by Shakespeare, virtuous characters and virtuous actions move slowly; speed is characteristic of the play's evil actions and their actors. What an audience approves

THE PLAY'S HIS THING Stephen Booth at the Blackfriars Conference, 2011. The literary critic's analysis of Shakespeare's "substantive nonsense" could be a model for cognitive science.

ERIC ROFFMAN - QPORIT

in one dimension of its experience is at perfect odds with what it approves in another." This, Booth maintains, is why we keep going to see *Macbeth*. And for him, the three-hour respite from the constraints of ordinary logical and moral systems is "an effectively miraculous experience."

COGNITIVE SCIENTISTS HAVE EXAMINED many of the elements that Booth discusses—wordplay, poetics, figurative language—but they haven't yet managed to integrate them fully into their theories of language. In some crucial areas, the scientists have yet to catch up with Booth.

In general, cognitive scientists tend to treat consciousness as a torch for illuminating language: pay closer attention, have a richer experience. Davis writes about the effects of Shakespeare mostly in terms of neurons and brains rather than humans and minds. But when he extends the terms of the discussion to include consciousness, he invokes a framework in which more neural activation in response to art implies more conscious awareness of its effects on us, and therefore a more meaningful poetic experience. And it makes sense to imagine engagement with art as involving lots of active, self-aware deliberation, with correspondingly high levels of neural activity ... doesn't it?

Yet Booth argues strenuously against this portrayal. His case for muted wordplay and unexploited paradoxes poses a more counterintuitive relationship between consciousness and language experience. Being too self-aware, he claims, can disrupt the experience of an unfolding verse and blind us to more subdued phenomena. (In recent years, neuroscientists have found that hyper-awareness can curtail subtle, subconscious activities, like reflecting on our surroundings and ourselves.) Returning to the example of *Macbeth*, Booth maintains that the subtle effects created by the dialogue, and the fact that their workings remain below threshold, are crucial to the experience of the play. The "miraculous experience" is attainable for audience members "only *because* they are oblivious to the logical conflict in their responses and to their achievement in tolerating its irresolution." We are provided with so much activity from so many overlapping and interacting relationships between words that we do not notice the jags and hiccups, nor our own proficiency in accommodating for them.

As a playwright and businessman, of course, Shakespeare had a serious interest in shielding his audiences from the mechanics of his verse. In addition to its concordance with the 16th-century concept of *sprezzatura*—lightness, ease, the ability to make even the most difficult things look effortless—a play crafted to maximize delight helped Shakespeare fill theaters in a way that a lot of visible sweating over the lines might not have. For every ingenious device that Booth describes in the verse, he brings as much attention to the effort that went into keeping it unobtrusive. His theory may explain the ineffable mind-states that poetry creates in us: poetic experience as the interaction of barely perceptible mental processes whose delicate, scintillating play is usually washed out by the spotlight of conscious attention.

What Booth so elegantly shows us is how Shakespeare can free us from ourselves. His lush, prismatic verse grants us "a small but metaphysically glorious holiday" from how we usually comprehend language, a holiday that is in turn "a brief and trivial but effectively real holiday from the inherent limitation of the human mind." Rather than plunging into the abyss of not-knowing, we soar above it. We are not falling, but flying.

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"HOW CROWDSOURCING TURNED ON ME"
ILLUSTRATION BY **TOMI UM**

Our Neanderthal Complex

What if our ancient relatives did "human" better?

BY LYDIA PYNE

IN AUGUST 1856, LIMESTONE QUARRY workers blasting out the entrance to the Feldhofer grotto in the Neander Valley of west-central Germany found a set of skeletal remains. Assuming the skull scraps, arm bones, ribs, and pelvis were from an ancient cave bear, the workers turned them all over to Johann Carl Fuhlrott, an amateur naturalist and local schoolteacher. Fuhlrott quickly recognized that the bones were in fact human-like, but in an unusual way: The skull was extremely thick, elongated, and had almost ridiculously pronounced brow ridges.

In June 1857, together with the famed professor of anatomy Hermann Schaaffhausen, Fuhlrott publicly announced that the bones represented an ancient race of humans. "The human bones from the Neanderthal exceed all the rest of those peculiarities of conformation which led to the conclusion of their belonging to a barbarous and savage race," the two researchers wrote.[1] The unique cranial morphology of Neanderthals was immediately interpreted as issuing from deficiencies in Neanderthal cognitive ability, and by the beginning of the 20th century, this was taken as a given: New Neanderthal specimens discovered across Eurasia did little to dissuade the paleo-intelligentsia from this thesis.

In 1908, for example, a Neanderthal skeleton was uncovered in France, outside of La Chapelle-aux-Saints; it was recovered *in situ*, as a burial, and, as such, indicated some sort of non-primitive, cultural behavior. The skeleton was promptly sent off for analysis to Marcellin Boule, the Director of the Laboratory of Palaeontology at the prestigious Musée National d'Histoire Naturelle. In his monograph, *L'Homme Fossile de La Chapelle-aux-Saints*, he concluded, not that the La Chapelle Neanderthal might have exhibited some signs of higher function, but that its severely curved spine, bent knees, jutting head, and low-vaulted cranium confirmed the primitive nature of the species.[2] His interpretation of the La Chapelle fossil set the paradigm for Neanderthal research for the better part of a century.

> "We see ourselves, for better or worse, in comparison to Neanderthals."

This view was echoed by museums and dioramas. When the Field Museum of Natural History opened its "Hall of the Stone Age of the Old World" exhibit in 1933, it featured eight dioramas, each one focused on a different type of prehistoric human. One diorama called "The Mousterian" showed a group of five life-size Neanderthal figures in front of a rock shelter. The museum guidebook, *Prehistoric Man*, explained the role of each figure: The elder Neanderthal man by the fire was the group's patriarch, his eldest son was standing guard, and so on. Although this scene humanized the behavior of Neanderthals, the guide left little to the imagination regarding the species' intelligence: "the prefrontal area, which is the seat of the higher faculties, was not fully developed in [Neanderthals], and had a protuberance similar to that found in the brain of anthropoids [great apes]. Furthermore, the lobe associated with the power of speech was little developed ..."

The rhetoric of the "savage" and "primitive" Neanderthal also informed the story of Neanderthal extinction, which happened 30,000 to 50,000 years ago.[3] Purported causes have oscillated from changing climates and inferior technologies to the species' hybridization, the advent of revolutionary cognition in *Homo sapiens*, and even a human-caused genocide. Many of these accounts assumed a lack of the ingenuity necessary for a species to be an evolutionary success—an ingenuity that *Homo sapiens* had. As the 1933 Field Museum's *Prehistoric Man* put it, "Man, small in number and physically weak in comparison with the creatures which surrounded him, was forced to use *ingenuity* and *his powers of reason*, in order to maintain himself in a hostile world."

Genius became the defining characteristic of humans' evolutionary achievement, and the narrative against which Neanderthals were measured. Even the language of extinction imbued Neanderthals with an aura of evolutionary fatalism: "demise," "fate," and "loss" helped us cast our interspecies interaction as a relationship between winners and losers. "It is not difficult to understand why the Neanderthals failed to survive," noted Richard Klein in the third edition of his seminal textbook, *The Human Career*, in 2009. "The archaeological record shows that in virtually every detectable aspect—artifacts, site modification, ability to adapt to extreme environments, subsistence, and so forth—the Neanderthals lagged their modern successors, and their more primitive behavior limited their ability to compete for game and other shared resources."[4]

The only problem? Much of our understanding of the Neanderthals has turned out to be wrong.

IN HIS CRITICALLY-ACCLAIMED *Neanderthal Parallax* trilogy, published in 2002 and 2003, science fiction author Robert Sawyer envisions an alternative evolutionary timeline. What if, in the glacial Pleistocene, *Homo sapiens* hadn't beat out every other member of *Homo*? What if, instead, Neanderthals had spent the last 30,000 years achieving a culture as sophisticated

AT THE BEACH The 1933 Field Museum diorama "Mousterian Group" showed a Neanderthal family in Gibraltar. This image is taken from the museums' visitors guide.

FIELD, H. & LAUFER, B. *PREHISTORIC MAN, HALL OF THE STONE AGE OF THE OLD WORLD* FIELD MUSEUM OF NATURAL HISTORY, CHICAGO (1933).

as our own? What if Neanderthals did "human" better?

Sawyer's plot might be far-fetched, but his vision of a blurred boundary between human and Neanderthal has increasingly become rooted in fact. By the 1960s, the first cracks appeared in the traditional "savage" and "primitive" Neanderthal narrative. Research that re-examined Boule's original studies revealed that humans and Neanderthals had a very similar locomotor pattern; pollen found at the Shanidar burial in Iraq was interpreted as flowers placed on graves (though this was later disputed); and the distributions of ages and disabilities at the Shanidar site suggested a system of Neanderthal social support.[5]

By the 1990s and early 2000s, research had firmly established that Neanderthals created complex tools, buried their dead, had an organized use of space, probably cared for the infirm, and perhaps even conversed vocally. Over the last decade, a host of sites, like El Sidrón, Riparo Bombrini, and Mezmaiskaya Cave (in Spain, Italy, and Russia, respectively), have offered more evidence—like specialized living areas in rock shelters and complex tool technologies—to indicate that Neanderthals were capable of sophisticated behavior.[6]

Just this year, researchers offered a series of tantalizingly detailed new insights about Neanderthal culture and Pleistocene lifestyles. Paleo-geneticists have lit up the public imagination with descriptions of the genetic overlap between modern humans and Neanderthals.[7] Excavations at Gorham's Cave in Gibraltar have suggested that Neanderthals exploited rock pigeon populations for food[8] and produced etched cave art[9] around 39,000 years ago. Clive Finlayson, the director of the Heritage Division of the Gibraltar Museum and Gorham Cave researcher, noted in an interview in *Nature*, "What is clear is that it [the etched cave art] is abstract, it's deliberate, and it speaks to their cognition in a way that brings Neanderthals, once again, closer to us."

The new findings have ushered a transformation of the Neanderthal from a knuckle-dragging savage rightfully defeated in an evolutionary contest to a distant cousin that holds clues to our identity. Where museums used to emphasize their primitive and brutal nature, modern exhibits evoke a feeling of belonging. "For Neanderthals, especially in museum exhibits, there's a sense of wanting to connect to them since they are so close to us," says Linda Kim, an art historian specializing in museum exhibits. "There's a deep longing or perhaps a sense of kinfolk."

The Hall of Human Origins at the Smithsonian Institution is a case in point. Opening in 2010, it combines a display of the actual remains of a Neanderthal from Shanidar, Iraq, with an exhibit where visitors can download an app to "transform themselves into an early human." Called MEanderthal, the app creates a composite of your face and an early hominin reconstruction. Paleo-artist John Gurche created bronzes, portraits, and reconstructions of many hominin species specifically for the exhibit. He describes the Neanderthal as "a behaviorally sophisticated kind of human ... I wanted to portray a being with a complex inner life. A distinct hairstyle ... and a deerskin hair band with a lined design, hint that this complex being has symbolic levels to his thinking."[10] This is a long way from Boule's 1957 description in his popular textbook *Fossil Men*: "There is hardly a more rudimentary or degraded form of industry than our Mousterian [Neanderthal] Man ... [The] brutish appearance of this energetic and clumsy body, of the heavy-jawed skull ... declares the predominance of functions of a purely vegetative or bestial kind over the functions of mind."[11]

IN STUDYING THE NEANDERTHAL, we have moved from one narrative, about human superiority, to another, about familial belonging. Both are old narratives and speak not just to the evolving archeological record, but to our desires and beliefs as subjective interpreters of that record. The first narrative was driven in part by a deeply embedded need to cast the evolutionary story of hominins around ourselves, and to be the geniuses in our own story;[12] the second, by a desire for self-discovery and rootedness. In each of them, the Neanderthal is a star character, a kind of phylogenetic foil. "We see ourselves, for better or worse, in comparison to Neanderthals," suggests Dr. Julien Riel-Salvatore, an archaeologist at the University of Montreal, specializing in the Paleolithic. "We want to see how we stand out."

What persists in both narratives, though, is a focus on intelligence. Article headlines about Neanderthals in popular and scientific circles today continue to use phrases like "more intelligent" and "sophisticated" in addition to "closer to us." Although less overt than Boule, this language continues to make it clear that entry into the club of *Homo sapiens* requires, if nothing else, a good head on your shoulders.

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The View

Halfway up the eastern slope of the cerebellum our expedition encountered a young scientist excavating a small tangle of neurons. Without looking up, the scientist said, “According to my calculations, this should be a child’s first steps.”

While traversing the inferior surface of the occipital lobe, we came across a giant electrical grid and monitoring system. A researcher stood at the control panel. As we passed, he muttered, “Perception,” as though introducing himself.

Knee-deep in the crystal clear waters of the pericallosal cistern, two grad students were panning for morality.

At the temporal-parietal junction, a group of young men and women in white lab coats were building a giant observatory to capture out-of-body experiences.

In the deepening gyral shadows, we continued upward. Just before dusk, we reached the summit. Despite the waning light, the view was stunning. I started to speak, but the expedition leader, a poet, put her finger to her lips and shook her head. For a time we stood in silence, taking in the history and future of man.

On our descent we passed a succession of researchers working beneath small circles of light cast by their halogen head lamps. We kept our distance, our gazes averted. In the darkness the specks of light rising toward the summit created the impression of a path.

I’ve been told that the researchers are still there.

—Robert Burton

ILLUSTRATION BY HANNAH K. LEE

Why the Chess Computer Deep Blue Played Like a Human

Randomness may be key to both human and computer creativity

BY DAVID AUERBACH

WHEN IBM'S DEEP BLUE beat chess Grandmaster Garry Kasparov in 1997 in a six-game chess match, Kasparov came to believe he was facing a machine that could experience human intuition. "The machine refused to move to a position that had a decisive short-term advantage," Kasparov wrote after the match. It was "showing a very human sense of danger."[1] To Kasparov, Deep Blue seemed to be experiencing the game rather than just crunching numbers.

Just a few years earlier, Kasparov had declared, "No computer will ever beat me."[2] When one finally did, his reaction was not just to conclude that the computer was smarter than him, but that it had also become more human. For Kasparov, there was a uniquely human component to chess playing that could not be simulated by a computer.

Kasparov was not sensing real human intuition in Deep Blue; there was no place in its code, constantly observed and managed by a team of IBM engineers, for anything that resembled human thought processes. But if not that, then what? The answer may start with another set of games with an unlikely set of names: Go, Hex, Havannah, and Twixt. All of these have a similar design: Two players take turns placing pieces on any remaining free space on a fairly large board (19-by-19 in Go's case, up to 24-by-24 for Twixt). The goal is to reach some sort of winning configuration, by surrounding the most territory in the case of Go, by connecting two opposite sides of the board in Hex, and so on.

The usual way a computer plays chess is to consider various move possibilities individually, evaluate the resulting boards, and rank moves as being more or less advantageous. Yet for games like Go and Twixt, this approach breaks down. Whereas at any point in chess there are at most a couple dozen possible moves, these games offer hundreds of possible moves (thousands in the case of Arimaa, which was designed to be a chess-like game that computers could not beat). The evaluation of all or most possible board positions for

ILLUSTRATION BY NEVER EVER EVEN

more than a couple of moves forward quickly becomes impossible for a computer to analyze in a reasonable amount of time: a combinatoric explosion. In addition, even the very concept of evaluation is more difficult than in chess, as there is less agreement on how to judge the value of a particular board configuration.

For humans, though, these games remain eminently playable. Why? Computer scientist and advanced Go player Martin Müller gives us a hint:

> Patterns recognized by humans are much more than just chunks of stones and empty spaces: Players can perceive complex relations between groups of stones, and easily grasp fuzzy concepts such as "light" and "heavy" stones. This visual nature of the game fits human perception but is hard to model in a program.[3]

In other words, Go strategy lies not in a strictly formal representation of the game but in a variety of different kinds of visual pattern recognition and similarity analysis: sorting the pieces into different shapes and clumps, comparing them to identical or visually similar patterns immediately available to one's mind, and quickly trimming the space of investigation to a manageable level. Might Kasparov have actually detected a hint of analogical thinking in Deep Blue's play and mistaken it for human intervention?

DEEP THOUGHT Garry Kasparov at the start of his sixth and final match against Deep Blue. He would go on to lose.

STAN HONDA/AFP/GETTY IMAGES

ANALOGY HAS A LONG history in thinking about thinking.

Cognitive linguists such as Mark Turner and Gilles Fauconnier, building off of the work of George Lakoff (*Metaphors We Live By*), have emphasized the analogical process of conceptual "blending" as being core to every level of human cognition, from discerning images to creative writing to applying mathematical concepts to the world.[4,5] Historian and philosopher Arthur I. Miller (*Insights of Genius*)[6] and historian Andrew Robinson both stress relentlessly creative, conceptual analogizing as being at the heart of scientific innovation and revolution.

But analogy presents a major challenge to computers, and even to the formal logic that undergirds computer science. The mathematician Stanislaw Ulam believed analogy was key to extending formal logic to encompass the whole world: "What is it that you see when you see? You see an object as a key, you see a man in a car as a passenger, you see some sheets of paper as a book. It is the word 'as' that must be mathematically formalized, on a par with the connectives 'and,' 'or,' 'implies,' and 'not' ..."[7]

Computers are notoriously bad at inferring analogical relationships, like grasping that a picture of a horse portrays an instance of the class of object called "horse." When humans look at a horse, we do not take it in bit by bit and analyze it; we instantaneously see it *as* a horse (or a car, or a plane, or whatever it may be) analogically—even in the presence of high degrees of variability.

Computer scientist and complexity theorist Melanie Mitchell, who studied under Douglas Hofstadter, has studied how computers can classify objects with the help of shape prototypes. These experiments use neural networks and a dictionary of "learned shapes" to match new shapes against. In a 2013 study, Mitchell made a startling discovery: If the algorithms' dictionary was removed and replaced with a series of random shape projections to match against, the algorithms performed equally well.[8] While intuition may suggest that the brain builds up representational archetypes which correspond to objects in the world, Mitchell's research suggests that pure randomness may have an important role in the process of conceptualization.

The extent to which these results speak to human analogizing is unclear. But they open the possibility that our process of analogy making may be even less rational and more stochastic than we suspect, and that the deep archetypes we match against in our brain might bear far less relationship to reality than we might think. Underneath our apparent rationality may lie neurobiological processes that look considerably closer to random trial and error. In this view, human creativity and randomness go hand in hand.

The power of randomness is amply visible in new approaches that have finally enabled computers to play games like Go, Hex, Havannah, and Twixt at a professional level.[9] At the heart of these approaches is an algorithm called the Monte Carlo method which, true to its name, relies on randomized, statistical sampling, rather than evaluating possible future board configurations for each possible move. For example, for a given move, a Monte Carlo tree search will play out a number of random or heuristically chosen future games ("playouts") from that move on, with little strategy behind either player's moves. Most possibilities are not played out, thus constraining the massive branching factor. If a move tends to lead to more winning games regardless of the strategy then employed, it is considered a stronger move. The idea is that such sampling will often be sufficient to estimate the general strength or weakness of a move.

If anything, Monte Carlo methods seem dumber still than computer chess approaches, because now instead of evaluating board positions en masse, computers are just playing out random (or at least partly-random) games and sampling the possibilities. It is a meta-strategy without a strategy! But Monte Carlo works better for high-branching games than more "strategic" approaches that attempt to make accurate evaluations of the strength of particular board positions.

What Kasparov might have sensed when he played Deep Blue is something that *appeared* like that creative randomness, which he took to be a "human" intuition of danger. Deep Blue programmer Feng-Hsiung Hsu writes in his book *Behind Deep Blue* that during the match, outside analysts were divided over a mysterious move made by the program, thinking it either weak or obliquely strategic. Eventually, the programmers discovered that the move was simply the result of a bug that had caused the computer not to choose what it had actually calculated to be the best move—something that could have appeared as random play. The bug wasn't fixed until after game four, long after Kasparov's spirit had been broken.

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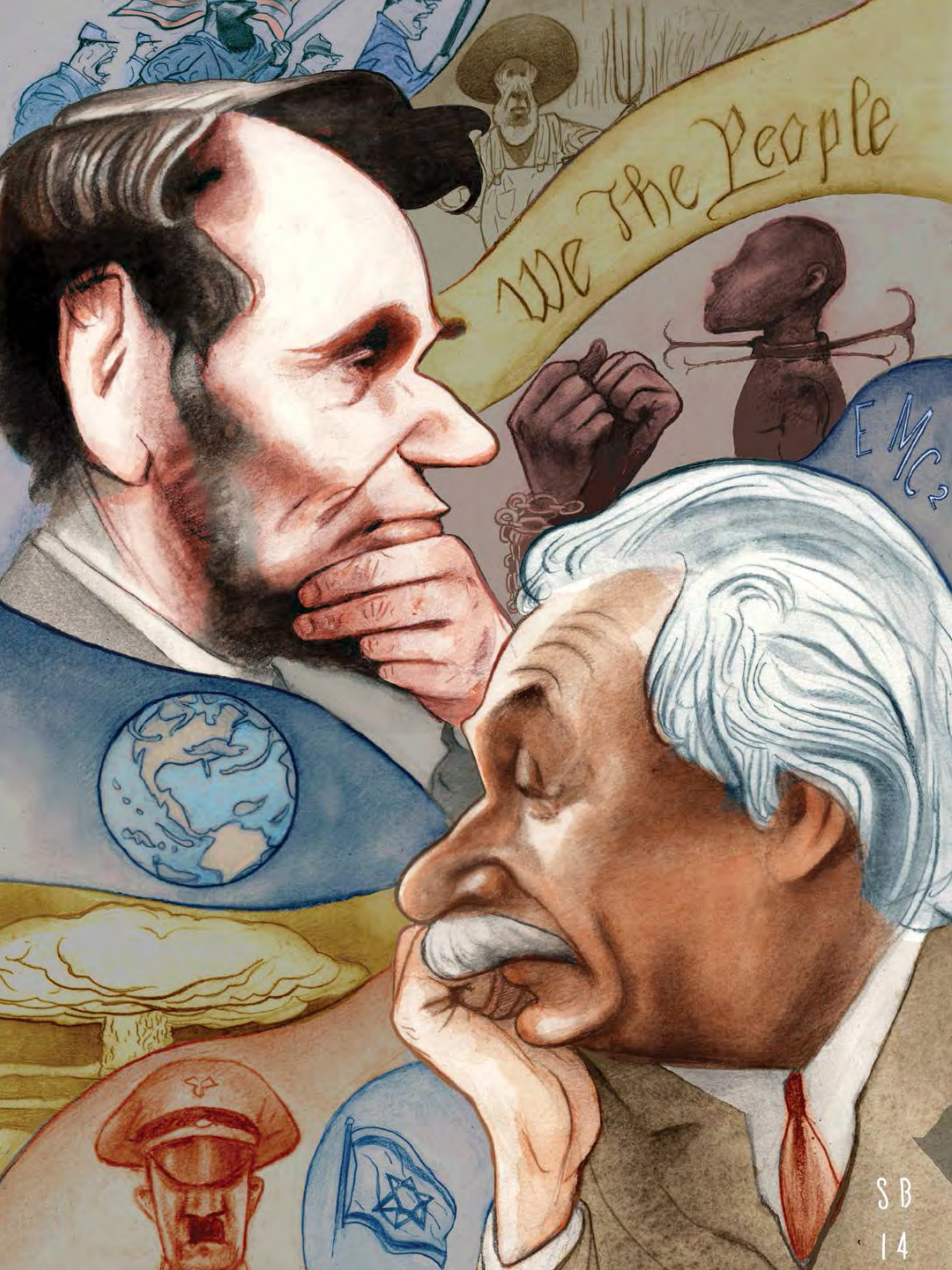
We The People
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The Common Genius of Lincoln and Einstein

The president and the physicist teach us a lesson about moral genius

BY ANDREW O'HEHIR

ABRAHAM LINCOLN WOULD STILL be remembered today as a self-taught prairie prodigy and an astute political operator who crushed the Confederate uprising, even without the Gettysburg Address, the Emancipation Proclamation, and the end of slavery. Albert Einstein would still be the most famous physicist of the 20th century, and the author of the most famous equation in history, had he not called on his fellow scientists to address the moral consequences of their discoveries, speaking out against war and nuclear weapons. But both men possessed a quality that went beyond their immense talents in politics and science and elevated them to world-historical stature: an ambiguous but distinctive quality that scientists, historians, and philosophers have begun to call moral genius. By suggesting that morality can, like math or chemistry or musical composition, admit of genius-level contributions, the phrase challenges us to reconsider the nature of genius itself.

Columbia University philosopher Elliot Paul observes that at first glance a great moral leader does not appear "creative" in the same sense as a revolutionary artist or a brilliant scientist. The ideas represented by Lincoln or Einstein or Mahatma Gandhi or Martin Luther King Jr., in their capacity as moral leaders, were not necessarily new. A great many 19th-century Americans were deeply uncomfortable with slavery and understood that it conflicted with the nation's alleged ideals on a fundamental level. Einstein was hardly the only person, or the only physicist, to notice that the immense scientific advance of splitting the atom threatened the human race with extinction. King and Gandhi personally experienced racial discrimination and saw it as a corrosive moral wrong that sickened entire societies, but they were certainly not alone.

What these people did that was creative and distinctive was to seize the moment—to recognize a great moral wrong and embrace the idea that they had a unique responsibility, and ability, to do something about it. Psychological theory on the subject of

ILLUSTRATION BY STEVE BRODNER

unusual creativity has often focused on the idea that genius is a self-created phenomenon. In the words of the late psychologist Howard Gruber, genius is best understood as "an organization that was constructed by the person himself in the course of his life, in the course of his work, as needed in order to meet the tasks that he encountered." (Gruber's gendered pronouns reflected standard usage at the time, highlighting the fact that women have historically been excluded from the category.)

Like high-achieving individuals in science or the arts, Paul suggests, moral geniuses are willing to stand against conventional opinion, often within their own nation or community, and seek to overthrow it. That kind of individual courage, we might say, becomes the subject or the text of the moral genius's greatness. While the specifics vary greatly, we could describe a moral genius as someone who rejects the innate caution and the hypocritical compromises of normative social morality. (King's "Letter From Birmingham Jail," his most sustained accomplishment in rhetorical prose, addresses precisely this issue.) "To become a moral leader is a demanding and inherently risky thing to do,"

> Like high-achieving individuals in science or the arts, moral geniuses are willing to stand against conventional opinion.

says William B. Irvine, a professor of philosophy at Wright State University and author of the forthcoming book *Aha! The Moments of Insight That Shape Our World*. "And moral leadership is most important in a situation where everybody is going to look down on you as a social traitor." Gandhi opposed not just British imperialism but also Hindu nationalism; Einstein was a lifelong Zionist who opposed the notion of Israel as a Jewish state; Lincoln's decision not to arrest or prosecute the Confederate leadership was derided by Northern radicals, and remains controversial among historians.

Irvine's book focuses on the moments of insight or clarity or special revelation that often seem to accompany history-shaping individual breakthroughs, whether in science, the arts, or the moral domain. Among numerous other examples, he considers the case of 18th-century British reformer Thomas Clarkson, who first adopted the anti-slavery position for strategic reasons, in an effort to win an essay contest as a Cambridge University student. Once he was rationally convinced of the rightness of the cause, Clarkson became consumed by the issue at a profoundly personal level, suffering from repeated nightmares about the horrors of slavery. "He tried to ignore it and push it off to one side, and it wouldn't let go of him," Irvine says. "The only way I can have peace in my life, he decided, is to become a moral warrior. Otherwise my conscience will never leave me alone."

In Lincoln and Einstein, we see both the striving, self-created individual that Gruber describes and some evidence of Irvine's "aha" moments. Years afterward, Einstein remembered the 1939 letter he wrote to Franklin D. Roosevelt, urging the United States to consider developing nuclear weapons, as the worst mistake of his life. It was certainly defensible in the context of the time, faced with the evidence that Hitler's scientists were also pursuing the A-bomb. Einstein had been a pacifist and an activist for social justice throughout his life, but his sense of personal responsibility for Hiroshima and Nagasaki clearly drove him to become a leading spokesman on the dangers of nuclear war and a founder of the anti-nuclear movement, which would grow to a global scale decades after his death and ultimately compel the American and Soviet superpowers to step back from the brink of Armageddon.

Similarly, Lincoln had opposed slavery his entire life on moral and philosophical grounds. But well into the war years he continued to view the subject in pragmatic, political terms, repeatedly stating he was willing to tolerate the evils of slavery in order to preserve the Union. Tony Kushner's screenplay for the film *Lincoln* offers a fictionalized "aha!" moment for Lincoln as he witnesses the carnage on the battlefield at Gettysburg and holds conversations with African-American soldiers. It's a pretty good guess, insofar as Lincoln seems to have arrived, over a short period of time in 1863, at the understanding that the only way to make the dreadful slaughter of the Civil War bearable was to attach it to a great moral cause. What you might call the second "aha!" moment lay in his realization that "preserving the Union" without uprooting the moral evil that had poisoned the nation was not a goal worth pursuing, and perhaps not possible.

In any event, the famously terse speech that Lincoln delivered at Gettysburg—quite likely the shortest speech ever delivered by an American president, and certainly the most far-reaching—was a work of immense moral and rhetorical genius. It recast the terrible, exhausting war as a purposeful struggle to redeem the promise of America, and it did more than that: It recast the entire history of the nation to that point as a revolutionary thought-experiment that had not quite reached its logical fulfillment. From that day forward Americans have thought of 1776 as the beginning of our nation's history (rather than the end of the Revolutionary War in 1783) and the high-flown philosophical language of the Declaration of Independence as central to our national identity. That speech was the work of someone with the peculiar ability to see history as if from the outside, seize its reins and change its course—and also someone willing to pay a grievous personal price for that historical role. It displayed intellect and openness in counterpoint, and a tremendously creative intelligence at work. We may attribute such an act of moral genius to unusual synaptic processing powers or to an invisible entity called the conscience. In either case it looks obvious and inevitable in hindsight, but required an extraordinary individual at the time.

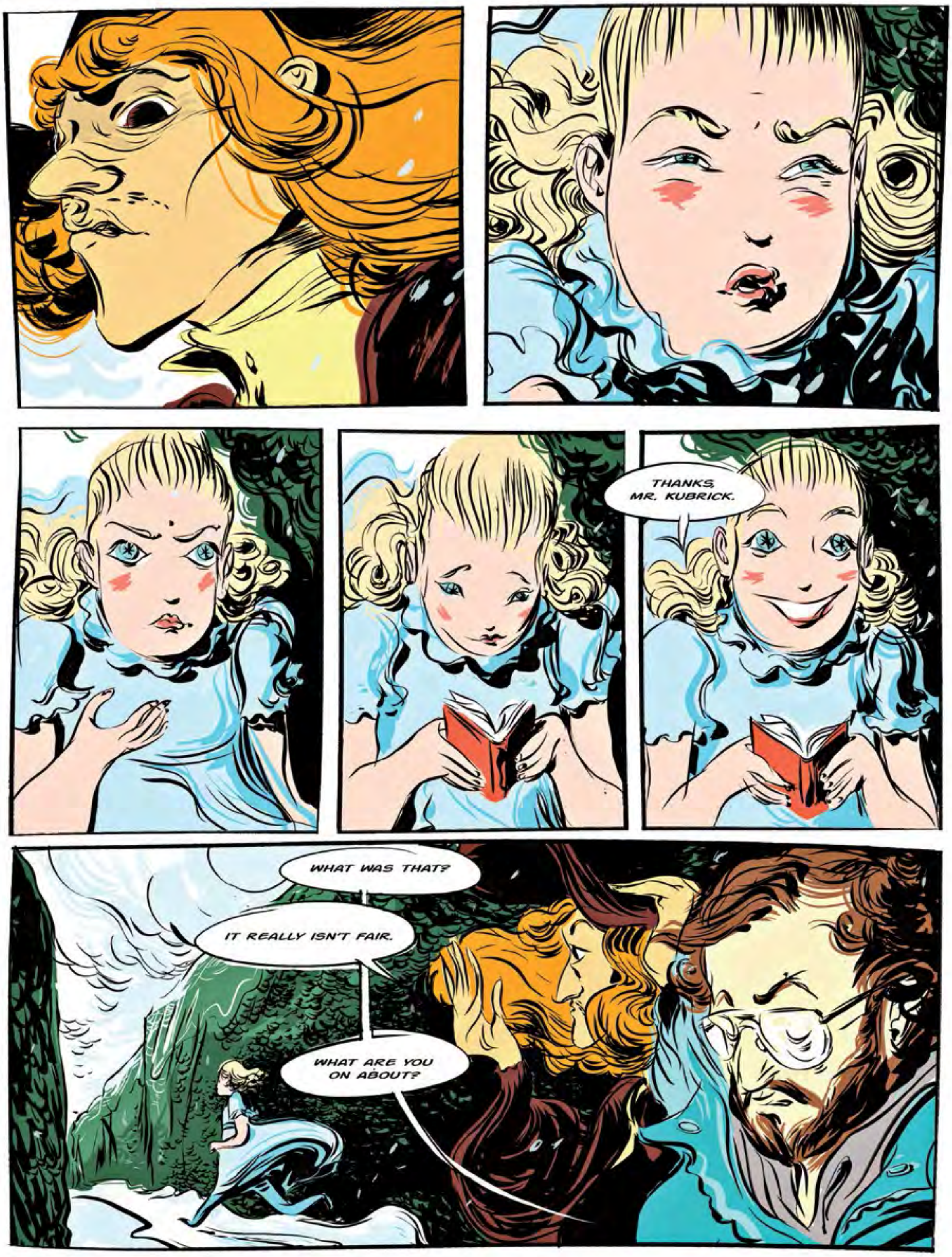
Some researchers now suspect that this ability to stand outside of one's immediate context and take a longer historical view, like other forms of genius, may have physical correlates in the brain. Neuroscientist Nancy C. Andreasen recently wrote that her study of the brains of highly creative people suggests that they excel at "recognizing relationships, making associations and connections, and seeing things in an original way—seeing things that others cannot see." In objective terms, this shows up as much stronger activations (compared to a control group) in the association cortices, extensive regions on the outer surface of the brain that "interpret and make use of the specialized information collected by the primary visual, auditory, sensory, and motor regions."

Andreasen's initial research has primarily focused on prominent writers and other figures from the arts, but she supports the idea that unusual creativity is likely to be a similar neurological and biochemical phenomenon across fields and disciplines. Intriguingly, she also says that her research supports the age-old connection between exceptional creativity and certain varieties of mental illness, especially depression and other mood disorders. This cultural stereotype goes back at least as far as the Greeks, and it would seem to fit the examples of both Lincoln and Einstein. The former was well known for his melancholic disposition, and today would likely be diagnosed with clinical depression, while the latter had a family history of schizophrenia and (in Andreasen's judgment) appeared to manifest some mild or borderline symptoms. (Martin Luther King suffered from depressive episodes, and attempted suicide at least once, and some evidence suggests that Gandhi also suffered from depression). Whether this connection is also rooted in brain activation patterns and processing speed is an unanswered but fascinating question.

Mental illness aside, three of the four people I have mentioned were assassinated by political opponents. If Einstein looks like a universally revered figure in the rear-view mirror, it did not always seem so during his life: He was the subject of extensive FBI surveillance and harassment, and consistently depicted as a traitorous or unpatriotic Communist sympathizer by right-wing critics. In this and many other respects, the moral genius reminds us of other genius tropes, like the misunderstood artist or the persecuted astronomer—such a person faces fierce opposition, and is not unfamiliar with suffering.

ANDREW O'HEHIR is a senior writer at Salon.com.


The ART of PAINTING
BARRIE POTTER
WESLEY ALLSBROOK
AND CHAPLIN SAYS TO ME--
CAN I HAVE YOUR AUTOGRAPH?
TRACER.


THANKS, MR. KUBRICK.
WHAT WAS THAT?
IT REALLY ISN'T FAIR.
WHAT ARE YOU ON ABOUT?


THE WORLD CAN BE SO FICKLE, STAN.
JOHANNES-
BARRY LYNDON.
NOT THIS AGAIN.
YOU COMMISSIONED A SET OF LENSES THAT ALLOWED YOU TO FILM SCENES LIT SOLELY BY CANDLE LIGHT.
YES. CARL ZEISS* HAD MADE-
AND FOR THIS, YOU'RE LAUDED AS A VISIONARY, A GENIUS.
AND I, HUNDREDS OF YEARS PRIOR, NO FORMAL TRAINING, DEVISE A MEANS** OF TRANSLATING ALL THE SUBTLETY AND GRACE OF THE WORLD WE SEE ONTO A CANVAS-
I SUPPOSE.
BEFORE ELECTRICITY, LET ALONE KINO FLO, HAD EVEN BEEN DISCOVERED, I MIGHT ADD- IN GLOWING, LIFELIKE ACCURACY.


AND YOU'RE ONE OF THE MOST LAUDED PAINTERS OF ALL TIME?
WHO'S BARELY RECOGNIZED AS HE WALKS DOWN THE STREET! I'VE MADE PEARL EARRING MORE FAMOUS THAN MYSELF.
AND NOW THAT THE WORLD MIGHT HAVE SOME INSIGHT INTO WHO I AM, INTO THE METHODS AND TECHNIQUES I USED, I'M CONSIDERED A CHEAT! A 'TRACER.'
AS IF MY METHODS AND INVENTIONS CHEAPEN MY WORK.
AS IF I'M ONLY WORTHWHILE AS SOME IDIOT SAVANT.
WHAT CAN I SAY?
MAYBE YOU SHOULDN'T HAVE KEPT EVERYTHING SO SECRET.
NO RECORDS, PEOPLE HAD NO CHOICE BUT TO ASSUME YOU WERE SOME SUPERNATURAL PAINTING MESSIAH.
WHAT'S THAT SUPPOSED TO MEAN?
SO I SHOULD HAVE BEEN LIKE YOU?
MADE MY WORK ABOUT MY METHODS AND TECHNOLOGY, SCREW THE CONTENT.
EXCUSE ME?


I FELL ASLEEP DURING BARRY LYNDON!
YEAH, WELL "PEAL EARRING" IS A BIT ONE NOTE.
I'M SORRY.
ME TOO.
YOU PAINTED WITH LIGHT.
I LIT WITH PAINT.
BESIDES, WE'LL NEVER HAVE ANYTHING ON THEM.

WESLEY ALLSBROOK is an award-winning illustrator living and drawing in Brooklyn, New York. She attended the Rhode Island School of Design, was high school valedictorian, speaks three languages, rides horses, and is currently composing her wordless memoir.

BARRIE POTTER wrote this comic.

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* To achieve the naturalistic look of his period epic *Barry Lyndon*, Kubrick modified three Carl Zeiss Planar 50mm lenses, originally created for the NASA Apollo program. Their huge aperture, designed to photograph the dark side of the moon, allowed Kubrick to capture an image without the bright electric lighting normally used on a movie set, remaining truer to the candle light that would have been available in the 18th century.

** While the methods behind Vermeer's paintings remain a mystery, inventor Tim Jenison devised a theory that Vermeer used a mechanical aid consisting of a camera obscura lens, a concave mirror, and an angled "comparator mirror" to allow him to duplicate the lighting and color of his subjects with total, unprecedented accuracy.

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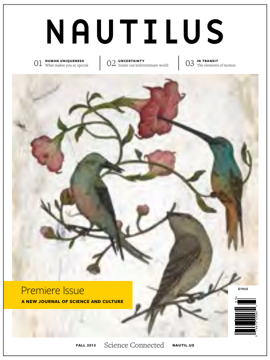

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Jonathan Weiner

The author of The Beak of the Finch *and* Long for This World *reflects on the themes in* Nautilus

INTERVIEW BY KEVIN BERGER

ON GENIUS

Darwin disclaimed genius. His personal motto was, "It's dogged as does it." He loved dogs, by the way, so that wasn't a total self put-down! But Erasmus hadn't thought of a mechanism for transmutation. He didn't know why life would change from generation to generation. Charles was much more patient. After the voyage of the Beagle, and a series of amazing eureka moments, he studied barnacles for eight years! He didn't just rely on the poetic inspiration of Erasmus or the hot flash of Alfred Russell Wallace, who, in a malarial fever, came up with a mechanism for transmutation. Darwin had all of that plus incredible persistence. That's a special kind of genius. And it's what led him to arrive at last at a substantial, well worked out argument for the origin and evolution of species.

ON BIG BANGS

As a reporter, the Big Bang for me was learning that evolution happens fast, that life is evolving all around us and we can watch. That blew me away. I was writing about two biologists, Peter and Rosemary Grant, who went to the Galapagos to study finches and discovered they could see Darwin's process unfolding before their eyes from one year to the next. Today scientists see that action at the level of genes and molecules. That makes this an incredibly interesting time—in a dark way. There's a hell of a lot going on, with the emphasis on hell. We're in the middle of a mass extinction. It's a new geological age, which is coming to be called the Anthropocene. You can see all this creation and destruction and it changes your whole sense of life. At the start of his essay "Nature," Emerson argued that great literature could come from America as well as from the Old World. He said, "The sun shines today also." In light of the news that evolution is taking place around us, I have the same feeling. I think most writers who follow science must feel this way.

ON NOTHINGNESS

When you talk to people who aren't enthusiastic about science, they feel threatened sometimes. At bottom is a fear that we are reducing ourselves to "nothing but." That was the reaction of Darwin's contemporaries: We're nothing but apes. Today people are afraid we're nothing but cells, nothing but molecules, nothing but atoms. Yet I think you can be a rational materialist and still feel that nothing-but-ness is wrong. The human brain has about 86 billion neurons. The *C. elegans* worm has only 302 neurons and every one of them has been numbered and mapped. Yet scientists still can't understand how the worm produces all that amazingly rich, graceful behavior, all those sinuous twisting and turnings. So we don't reduce ourselves to nothing when we look at our individual neurons. We are looking at working parts of something so phenomenally complicated and beyond our understanding that we should only feel awe, not despair.

ILLUSTRATION BY ANDY FRIEDMAN


Science minded
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