NAUTILUS

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Alchemy Reborn

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Convergences

AS THE PREMIER *NAUTILUS QUARTERLY* began reaching readers, we started to see pictures. On Twitter, Instagram, and Facebook, our front cover looked back at us, sitting on couches and coffee tables around the world. Look, the pictures seemed to say, how pixels have been made into paper, and the fleeting into the permanent! We were gratified by the response, of course. It sharpened for us the value of the printed word.

How appropriate, then, that the winter 2014 *Quarterly* cover feature picks up this same theme. In it, science writer Mark Anderson digs into the written correspondence between Albert Einstein and physicist Ernest Sternglass to construct a story that begins with ancient alchemy and culminates in an unlikely, potentially revolutionary energy technology. Since we at *Nautilus* love convergence, you can imagine how pleased we were: Here were the winter *Quarterly's* three themes (The Unlikely, Fame, and Secret Codes), discovered through the handwritten word, mixed into a single narrative, and printed for our readers.

The truth is that these convergences show up all the time, both by design and by surprise. In his story on the beginnings of modern probability in section 4 (The Unlikely), Slava Gerovitch describes the Russian mathematician Andrei Kolmogorov analyzing poems with computers. In section 6 (Secret Codes), Alan Brown explains how computers can be taught with poems, and how that is similar to teaching high school students. In section 5 (Fame), Jessica Seigel takes us into the life of a high school student with 2,000 Twitter followers. And so on. That is the *Nautilus* mission: to provide those categories and stories which reveal a remarkably connected world.

Welcome to the winter 2014 *Nautilus Quarterly*.

—Michael Segal

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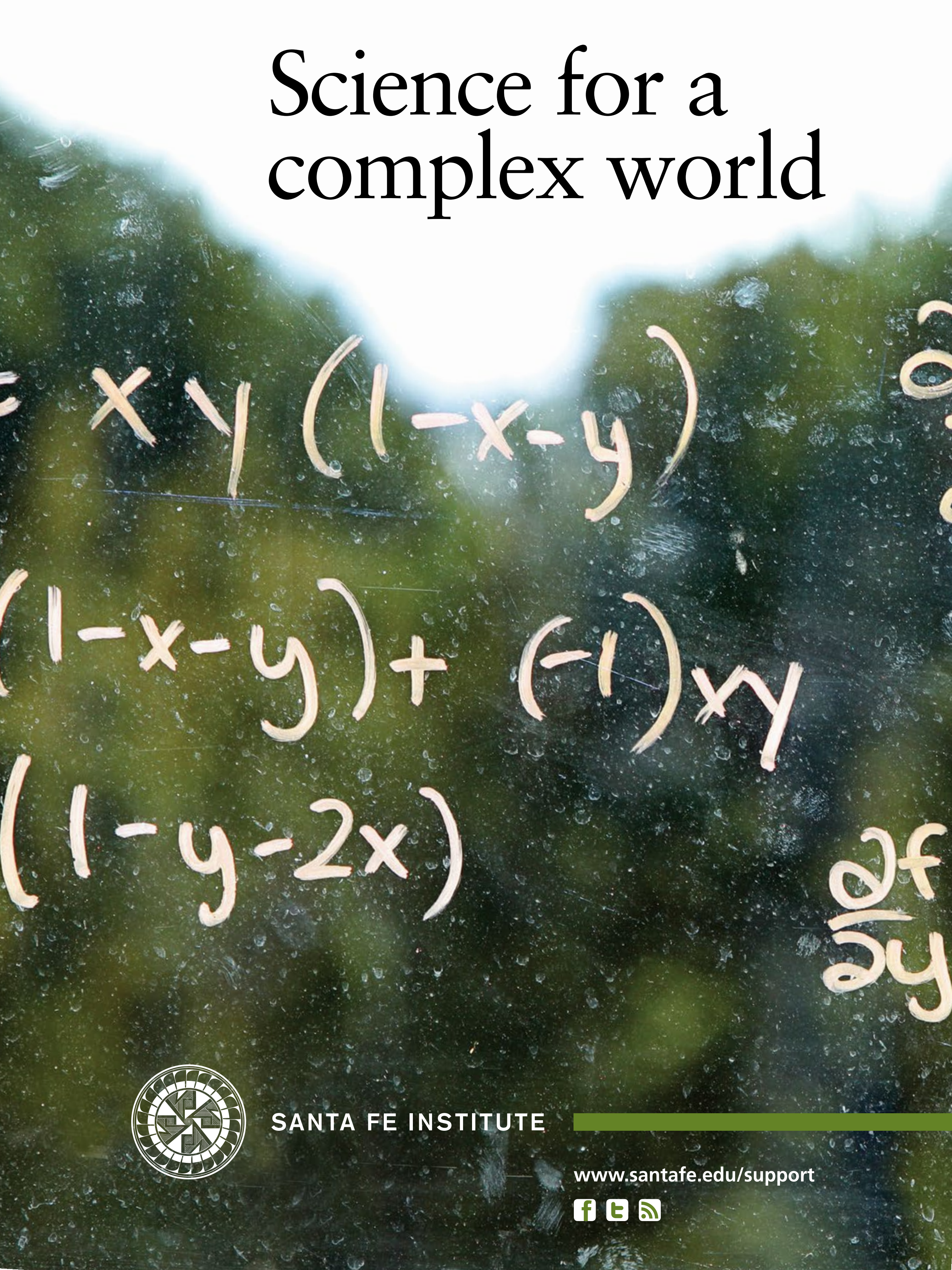
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THE ASCENT OF MAN
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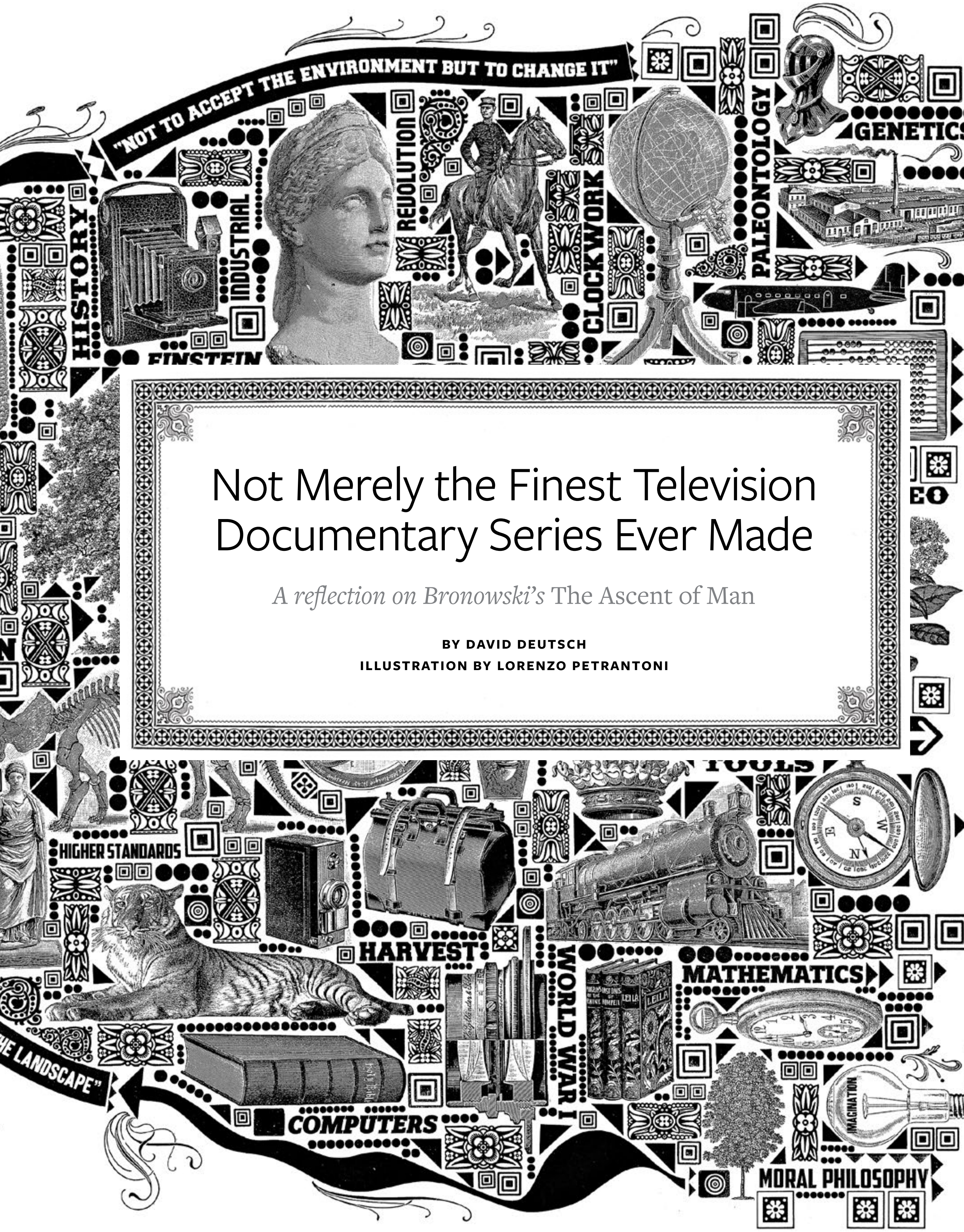

Not Merely the Finest Television Documentary Series Ever Made

A reflection on Bronowski's The Ascent of Man

BY DAVID DEUTSCH
ILLUSTRATION BY LORENZO PETRANTONI

A **RANGE OF DARK HILLTOPS** appears against a dawn sky. On a ridge in the far distance we can discern a human silhouette. It is someone telling us about the uniqueness of Man. "Man…" says the tiny figure in the landscape, "is not a figure in the landscape…"

"He is the shaper of the landscape," continues Jacob Bronowski, dwarfed by the looming hills that have not been reshaped since the last ice age.

When a narrator expresses a paradox, it should be regarded as a promise to explain something amazing. Bronowski, in this historic 13-part television documentary, delivered on his promises.

He was a one-off. A patrician British academic, he had arrived in Britain at the age of 12 in the aftermath of World War I, speaking no English. He and his family were Jewish refugees from Łódź in the Russian Empire (now Poland). One of the 20th century's most eloquent advocates of Western values, he was denied senior positions at British universities because (according to his daughter, the historian Lisa Jardine) MI5 mistakenly suspected him of being a communist sympathizer. A powerful intellect of unusual breadth and originality, he was never lucky enough to make the spectacular discovery that would have got him recognized as a *great* mathematician or scientist, but he made contributions to mathematics, poetry, paleontology, history, moral philosophy, and—during World War II—strategic bombing. Despite his hatred of war in general, he believed it would be pious humbug to stand aside from making the world a better place through winning a war.[1] He wrote books (mostly collections of his electrifying public lectures) and became a respected media pundit. But he is, rightly, best known for his last project, *The Ascent of Man* (1973), in my view the finest television documentary series ever made.

It came about as a sort of reply to Kenneth Clark's 1969 series *Civilisation*, itself a very successful documentary, but one that had been criticized for identifying "civilisation" almost exclusively with art (and European art at that), barely mentioning science. So David Attenborough, at that time the controller of BBC2, who had commissioned *Civilisation*, looked around for a scientist who could restore the balance by explaining science on television as Clark had explained art, and demonstrate to those steeped in the humanities that scientific knowledge is both thrilling and momentous. Bronowski, with his cross-disciplinary qualifications, was a natural choice, and turned out to be perfectly suited to that task. For in Bronowski's scheme of things, scientific discovery and artistic achievement—and moral and political progress too—are all integrated in the most detailed, practical way. For example, while the *truths* of science are morally neutral, the *practice* of science absolutely depends on certain values. It cannot continue unless independence of thought, the rejection of authoritative sources of truth, and tolerance of dissent are valued and actively practiced by the scientific community. Nor can the wider society make progress in the longer term unless it is able to do as science does: confront its own constitutive ideas with reality and change them creatively when they fail.

Bronowski saw the purpose of art as being the same as that of science: to give meaning and order to our experience by revealing hidden structure beneath the appearances. That conception gives an objective meaning to progress in those fields. Moreover, neither a scientific discovery nor a work of art can be made by merely "copying nature," for appearances are deceptive, traditions flawed. Hence a system of open-ended

1. See Bronowski's essay, *The Dilemma of the Scientist* (1956)

We have ascended in that sense, so that by now we could, if we wished, shape mountains on the moon, and live there.

self-correction is needed. Creativity and boundless imagination are as essential in the mathematical sciences as in the humanities; criticism and testing in art just as in science.

The Ascent of Man conveys this unity in a beautifully explained account of the pivotal steps in the history of ideas. But Bronowski's agenda was deeper and more urgent than that. Though he expressed it with characteristic understatement, his was a message of rebellion, a bold attempt to correct one of the great misconceptions of modern times and single-handedly to redirect the great river of intellectual history.

The misconception might—if its perniciousness were generally acknowledged—be called *antihumanism*: the pattern of ideas that disparages the human species, jeers at its claims to superiority over other species, or to any special entitlement, glories in its cosmic insignificance, and reinterprets its advent as nothing special and its subsequent progress as mostly illusory or fraudulent—and thus in all these senses, denies its *ascent*. Antihuman ideas would have seemed wicked or insane to the great majority of thinkers since the Enlightenment at least. But during Bronowski's lifetime, many of them had become mainstream, to the extent of being taken for granted in academic and everyday discourse. So Bronowski's rebellion is already there in his title: *The Ascent of Man*. He says that it refers to the "brilliant sequence of cultural peaks"—such as the invention of stone tools, agriculture, cities, and modern science—by which humans have learned how "not to accept the environment but to change it," thereby improving our lives. And that this progress, despite continual setbacks, has been cumulative for as long as our species has existed.

Think again about those hills of Bronowski's. Humans really do have the ability to shape them—for instance into fortresses, or temples, or stepped terraces for growing rice. Or to dismantle an entire hill and rebuild it somewhere else as a pyramid or a great wall. Shaping hills (or valleys, or forests) was in fact among the earliest and crudest of our distinctive achievements. If those hills did happen to be unchanged since the ice age it was only because human beings had happened to decide to leave them alone and to shape something else. But what conclusively resolves the paradox is not so much that we can shape our environment (after all, even ants build anthills) but that we shape it into novel forms, with novel functions and purposes, and choose whether and how to make the changes, and invent new purposes (such as scientific research, art, and literature) and new behaviors (such as farming, city-dwelling, and engineering) that enable us to thrive in the formerly lethal environments that we have shaped.

We have ascended in that sense, and improved our ability to do so, incrementally since prehistoric times, and ever more rapidly of late, so that by now we could, if we wished, shape mountains on the moon, and live there. And if we choose to continue our ascent, we shall soon be able to reshape anything from the scale of molecules (nanotechnology) to that of planets (terraforming and geoengineering) for our convenience and delight.

"The Ascent of Man" is also a scholarly pun. It refers to Charles Darwin's book *The Descent of Man* (1871), which defended the proposition that humans are descended from other animals. Bronowski of course had no quarrel with the "descent of Man" in that sense: It was essential to his world-view. But he did want to refute the slew of antihuman fallacies and misconceptions that it had inspired. For instance, the fallacy that since we are descended from animals, we

In all respects, we were worse off than we are now.

should expect to explain something about the roots of warfare by studying the fight-or-flight responses of bison; about adultery by studying the mating behavior of chimpanzees; about nation-states by studying the territorial instincts of birds, and so on. Books claiming to do so, such as Robert Ardrey's *The Territorial Imperative* (1966), Konrad Lorenz's *On Aggression* (1966) and Desmond Morris's *The Naked Ape* (1967), had been enthusiastically received. Their shared approach, of reinterpreting human social and political behaviors as being due to inherited remnants of animal instincts, soon came to dominate both public and academic discourse about human nature.

But in Bronowski's view, that approach is a nonsense and a travesty. His argument (one of the delights of *The Ascent of Man* is that it consists entirely of argument) begins by directing our attention away from the common heritage of animals and toward one particular *difference* between humans and all other present-day species: Every other species is exquisitely adapted by evolution to a certain range of environments, and to a certain range of lifestyles that it is genetically programmed to act out in them. But evolution "has not fitted Man to any specific environment. On the contrary… he has a rather crude survival kit. And yet… one that fits him to all environments."

How exactly this unique "survival kit" works is still mysterious, but we know that it confers an ability to use imagination, reason, and critical thinking, with which our ancestors could improve their ideas; and it confers the "emotional subtlety and toughness" to apply those ideas to improve the landscape to meet their objectives. And to improve those objectives themselves to create new and better ways of life.

This was of course a biological adaptation, encoded in DNA. But it was fundamentally different from all other adaptations in the biosphere. For it enabled, for the first time, further complex adaptations to be encoded, and improved, independently of DNA. Improving genes by biological evolution requires vast numbers of individuals to die for every scintilla of progress made. But the ability to encode whole new patterns of behavior and to pass them on by cultural means finally disconnected *progress* from *death*. As Karl Popper put it, we humans can "let our ideas die in our place." And this set in motion two radical new forms of evolution which are millions of times more rapid, and infinitely more powerful, than that of genes, namely, the evolution of ideas in individual human minds, and the evolution of culture.

If you want to know how bison, chimpanzees, or birds lived 10,000 years ago you need only study how they live now (in the wild). But for humans, you would learn nothing by that method. Ten thousand years ago

PHOTO BY TONY EVANS/TIMELAPSE LIBRARY LTD/GETTY IMAGES

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we lived in very different surroundings, made a living in different ways, had quite different economic and family relationships, and pursued different objectives. In all these respects, we were worse off—in some of them brutally, almost unimaginably worse[2]—than we are now. In another thousand years, or even a hundred, we may have changed as much again. If we then look back to try to understand the changes, we shall not find the explanation written in our genes.

The fitness "to all environments" that our new adaptation conferred—the *universality* of the human condition—has disconnected humans from their genetic inheritance. The behavior, lifestyle, abilities, and limitations of all other species are indeed explained entirely through the information in their DNA and the forces of natural selection that created it in their ancestors—that is, through their descent (in Darwin's sense). But what is important about humans can only be understood through their ascent (in Bronowski's).

Yet ascent is far from inevitable. Our ancestor and cousin species, who already had our survival kit, can hardly ever have used it for making progress. That is why those species are all extinct. We are the only species left on Earth with the capacity for taking control of our environment and lifestyles, and improving both on less-than-geological timescales. Even we did so only sporadically until the current spate of rapid progress, brought about by the scientific revolution and the Enlightenment.

These fits and starts were possible because, unlike every other survival kit in the biosphere, ours does not come with inborn knowledge of when to use it and what to use it for. It couldn't, because it includes the ability to change those things too. The propensity to use it to create progress is itself cultural, but most cultures in history have not valued or protected the behaviors that permit progress.

The Ascent of Man depicts many different cultures and societies. Bronowski describes their achievements with admiration and their predicaments with compassion. But his reason for discussing them is always to *judge* them—and always according to his explanation of whether, and how, they were capable of making

2. If you need sobering up in this regard, read Steven Pinker's 2011 book *The Better Angels of our Nature*.

progress. Thus, his rebellion defies a further taboo: *cultural relativism*, the idea that there is no such thing as one culture or society's values and traditions being better than another's. And therefore that objectively there is no such thing as progress either—no ascent—only the meeting of some culture's preferences, which another may loathe.

Aren't people "*basically* the same everywhere?" In Bronowski's view, individual people aren't basically anything, because their basic aptitude is universal. But in regard to cultures, Bronowski draws an uncompromising distinction between those that facilitate ascent and those that do not.

Filming the last remnants of an ancient horse-based culture in Afghanistan, Bronowski did not regret its decline. On the contrary, instead of applying the customary condescending doublethink towards primitive cultures, Bronowski traced the 5,000-year history from the earliest gangs of horsemen who stole from farmers what they could not produce themselves, to Genghis Khan, the terror of medieval civilization, and does not hesitate to classify that entire strand of cultural history along with Stalinism and Nazism as an archetypal enemy of the ascent of man. And the Nazi tank as the descendant of the war horse. "War," says Bronowski, "is not a human instinct" (this was a sideswipe at Lorenz and all who wish to see the animal mind inside the human), "it is a highly planned and cooperative form of theft." Similarly, Bronowski dared to stand in front of the great stone statues of Easter Island and declare that "These frozen faces… mark a civilization which failed to take the first step on the ascent of rational knowledge." Bronowski said, "I am fond of these ancient, ancestral faces, but in the end, all of them are not worth one child's dimpled face," for one human child—any child—has the potential to achieve more than that entire civilization did. Yet "for most of history, civilizations have crudely ignored that enormous potential… children have been asked simply to conform to the image of the adult." And thus ascent has been sabotaged or frozen.

Continued ascent will depend on adopting Bronowski's unified understanding that human values are not arbitrary nor science merely utilitarian: that there is a truth of the matter in cultures just as in scientific theories. That these truths are not obvious nor mechanically obtainable in either case, but can be approached only through institutions of relentless error-correction including those of science and of an open society. Bronowski spoke of peaks, but there have been many troughs too. Today, civilization still has enemies. There are still those who devote their creativity to the archaic objective of resisting new ideas. More dangerously, in my view, the many-stranded civilization of reason and science that has so powerfully promoted ascent in recent centuries still sits on the unstable fence between its aspirations for progress and the specious comfort of stasis. Two hundred years after the Luddites, it is still not sure whether labor-saving devices cause wealth or poverty. Two hundred years since Malthus, it has still not realized that the recipe for doom is not "too many people," but too few ideas. After 300 unprecedented years of sustained progress, it is still tempted to revert to its predecessors' educational priorities, namely to produce "higher standards" (i.e. more standardized children). And after 50 years of conservationism, it is no longer sure whether it is better to kill a herd of elephants or a child. Most dangerous of all, it is no longer even sure whether its own spread—to other cultures, or to other planets and star systems—would be a good thing.

Go forth, therefore, and watch *The Ascent of Man*.[3] If you have already done so, watch it again.

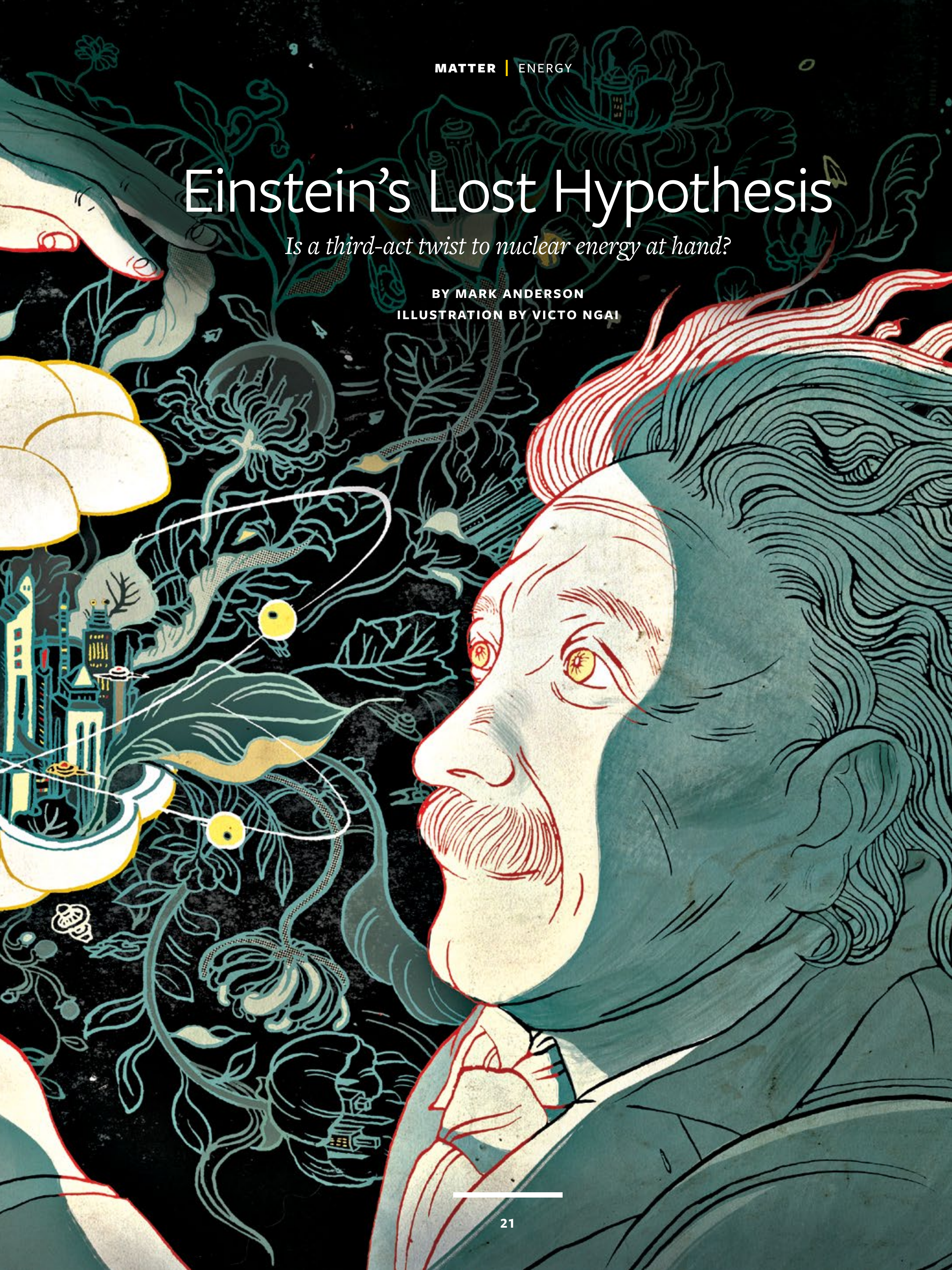
DAVID DEUTSCH has done seminal work on quantum computation and is a member of the Centre for Quantum Computation at the Clarendon Laboratory, Oxford University.

3. Or read the book (which is an almost verbatim transcript of the series).

Einstein's Lost Hypothesis

Is a third-act twist to nuclear energy at hand?

BY MARK ANDERSON
ILLUSTRATION BY VICTO NGAI



WHEN ERNEST STERNGLASS WALKED up the steps at 112 Mercer Street in April 1947, he knew it would not be a normal day. Like a church deacon summoned to meet the Pope, Sternglass—a 23-year-old researcher at the Naval Ordnance Laboratory in Washington, D.C.—had arrived in Princeton, N.J., at the invitation of its most renowned resident, Albert Einstein. Having completed only a bachelor's degree in electrical engineering, he had written to Einstein earlier that month about the work he was doing in his lab. To his great surprise, not only did Einstein promptly write back, he requested that Sternglass visit Princeton to discuss the work in person.

What Sternglass didn't know is that his visit to Einstein would set off a chain of correspondence, involving both an unpublished experiment (his) and an unpublished hypothesis (Einstein's) that together may constitute one of the century's most important disregarded pieces of science. The reason why the science was overlooked is plain enough: It was at least a generation ahead of its time. Now, more than half a century later, the work is being re-examined, with potentially profound implications for sustainable energy production. For Sternglass was to discover how to create free neutrons with household wall socket evergy levels—and Einstein was to explain why.

On that spring day in 1947, though, Sternglass was a humble visitor to the St. Peter's Basilica of physics. Having arrived in Princeton, he knocked on the door of the clapboard house, was let into the foyer by a secretary, and was soon confronted with the now-famous silhouette: an elderly man with a frizzy-haired halo, wearing an old sweat suit and bedroom slippers.

Sternglass had contacted Einstein because his lab in Washington was investigating how electrons are ejected from a metal when hit by a beam of electrons. The Navy wanted to understand this process better so they could develop night vision cameras, photography, and video that would be sensitive to the infrared light given off by body heat.

At first blush, Sternglass' findings might seem like just a military curiosity, hardly worthy of reaching out to the architect of space-time itself. But Einstein had won his Nobel Prize for a theory explaining a phenomenon related to the Navy research: the ejection of electrons from a metal illuminated by a beam of ultraviolet light, a process called the photoelectric effect. Sternglass had begun to suspect that the theory that explained his process—called secondary electron emission—was simply wrong. "Here I was, in my early 20s," Sternglass writes in his 1997 memoir *Before the Big Bang*, "without any advanced education in physics, about to ask the most renowned scientist in the world since Newton what he thought about my ideas."

The two, at Einstein's invitation, walked out to the backyard at 112 Mercer Street. Einstein cherished the opportunity to stroll with guests through his modest but beloved gardens. Sternglass found a point of commonality with his host. "We had a small garden in the suburb of Berlin where my father had built a summer home," Sternglass recalls. Both men were also native Jewish Germans who had escaped Nazi Germany in the 1930s, when there was still a chance to flee. Einstein cancelled his appointments for the rest of the afternoon.

Sternglass explained to Einstein how the latest theory of secondary electron emission was, ironically, too much like Einstein's own model of the photoelectric effect. Einstein's photoelectric theory considered just the outermost electrons in an atom, furthest from the nucleus. This was a safe assumption, and one borne out by today's science. But an electron and a photon are different things. Electrons can pack more of a punch than UV light, and therefore can penetrate deeper into the atom. So every electron orbiting the atom has to be accounted for in a realistic theory of secondary electron emission, Sternglass said. "That sounds reasonable to me," was Einstein's reply.

The conversation moved on to something near to Sternglass' heart: nuclear particles, and in particular, the neutron. Neutrons are agents of transmutation: They can transform one element of the periodic table into another. It was known at the time that the proton and neutron, which sit snugly next to each other in an atom's nucleus, could transform into one another if paired with an electron. In this way, one could add a neutron to a stable isotope of carbon (with, say, six protons and seven neutrons in its nucleus) to create the unstable isotope, carbon-14, which has six protons and eight neutrons. After a while (on average 5,730 years), carbon-14 spits out an electron to make a stable isotope of nitrogen, with seven protons and seven neutrons. Here, then, was another connection to Einstein: Isaac Newton, whose laws of physics Einstein showed to be incomplete, was obsessed with the transmutation of elements (a part of the ancient tradition of alchemy), and kept one of the largest alchemical libraries of his time.

Sternglass had worked with Einstein's theory of relativity, and had arrived at solutions to its equations that depicted stable, orbiting configurations of an electron and its antimatter counterpart, the positron. He interpreted these orbiting pairs as being equivalent to protons and neutrons. Today we understand these models to be creatively fascinating, but also incorrect (quarks make up protons and neutrons).

Nevertheless, it led Sternglass toward a crucial hypothesis. If neutrons and protons are indeed nuclear cousins differing in their makeup by just one electron, as Sternglass' model suggested, then there could be a backdoor way of making neutrons out of protons and electrons. Einstein, too, had been wrestling with the nature of the electron, which leaves behind just two photons after colliding with its antimatter counterpart, and not a bestiary of particles like the one resulting from a proton-neutron collision. Was the electron a breed apart?

Within a few years, Sternglass would be colliding electrons with protons at energies too low to be considered interesting, and reporting some surprising results

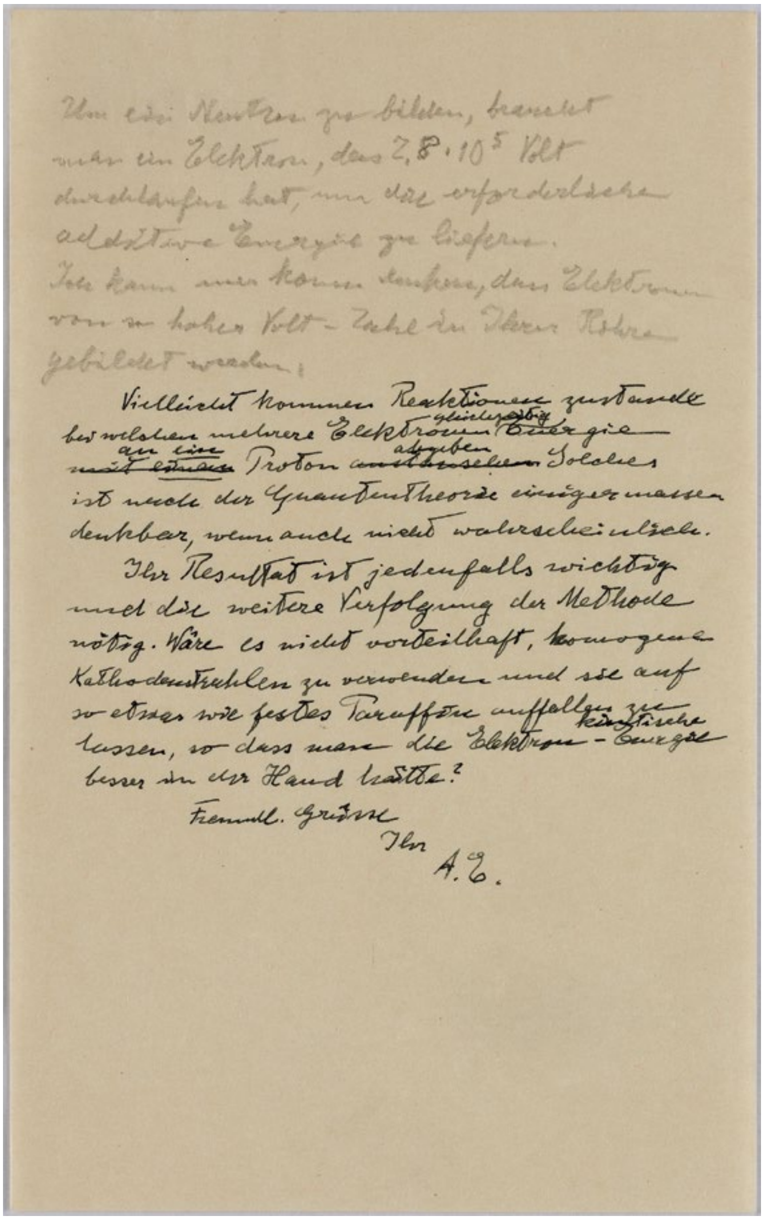
Neutron transmutation could in principle produce precious metals—the wild dream of medieval alchemists.

back to his mentor in Princeton. Einstein, for his part, saw promise in the young engineer. His parting advice was surprising: "Don't do what I have done," Einstein told Sternglass. "Always keep a cobbler's job where you can get up in the morning and face yourself that you are doing something useful. Nobody can be a genius and solve the problems of the universe every day."

Sternglass heeded the advice. Rather than enrolling in a pure physics graduate program, he entered the Ph.D. program in the new department of engineering physics, at his undergraduate alma mater, Cornell University. His graduate advisor was a Manhattan Project veteran, Phillip Morrison, who shared an office with another bomb veteran, Richard Feynman. Morrison told Sternglass he could run his neutron experiments so long as Sternglass also worked on the rather more conventional topic of secondary electron emission. Sternglass agreed.

On Nov. 19, 1950, Sternglass wrote a letter to Einstein telling him of his latest work. The letter—today in the Einstein Archives in Jerusalem—reveals an eager young physicist who was clearly waiting for the right moment to reconnect with a special correspondent. "I have been fortunate to be able to solve the secondary emission problem," Sternglass wrote. "Since you were one of the first to encourage me in my approach, I felt I wanted to tell you very briefly what I found." Thus resumed the correspondence between master and student.

Once Sternglass had a firm footing on the secondary electron emission problem, he turned his attention toward the ideas about neutrons and electrons he'd discussed with Einstein. And he wrote to his mentor as



Um ein Neutron zu bilden, braucht man ein Elektron, das $2,8 \cdot 10^5$ Volt durchlaufen hat, um die erforderliche additive Energie zu liefern.
Ich kann mir kaum denken, dass Elektronen von so hoher Volt-Zahl in Ihrer Röhre gebildet werden.

Vielleicht kommen Reaktionen zustande bei welchen mehrere Elektronen gleichzeitig Energie an ein Proton abgeben. Solches ist nach der Quantentheorie einigermassen denkbar, wenn auch nicht wahrscheinlich.

Ihr Resultat ist jedenfalls wichtig und die weitere Verfolgung der Methode nötig. Wäre es nicht vorteilhaft, homogene Kathodenstrahlen zu verwenden und sie auf so etwas wie festes Target auffallen zu lassen, so dass man die Elektronen-kinetische Energie besser in der Hand hätte?

Freundl. Grüsse

Ihr

A. E.

FROM MENTOR TO STUDENT On August 26th, 1951, Sternglass sent Einstein a letter detailing his seemingly impossible neutron data. This letter, dated four days later, was Einstein's reply.

soon as he had experimental results he felt confident in.

In a letter to Einstein dated Aug. 26, 1951, Sternglass wrote, "You may be interested to learn that in the course of the past two months, I have been able to obtain experimental evidence for the formation of neutrons from protons and electrons in high-voltage hydrogen discharge."

Sternglass' neutron experiment consisted of an evacuated glass tube less than a foot long filled with hydrogen gas. He fired an electron gun, not unlike the type found in old tube TV sets, through the gas and at thin foils of silver and indium at the end of the tube. There was no known way that an electron beam of the energies he was studying (about 35,000 electron Volts) could have induced any radioactivity in the foils. Nevertheless, time and again, that is what he observed. When he ran a control experiment with the beam passing through regular air, the foils did not become radioactive.

The radioactive signature suggested that the two stable isotopes that make up silver (silver-107 with 60 neutrons and silver-109 with 62 neutrons) were undergoing transmutation. Adding a neutron to each would produce silver-108 and silver-110 isotopes, which are unstable. When silver-108 decays, it gives off an electron (or beta particle) in, on average, 2.3 minutes. The leftover atom becomes the stable isotope cadmium-108. Silver-110 is more short-lived, beta decaying into cadmium-110 in just 24 seconds. "I should expect to observe a decay lasting of the order of 3-4 minutes," Sternglass wrote in his lab notebook. He'd seen just that. His silver foil was acting precisely as if it'd been bombarded by low-energy neutrons.

But this flew in the face of conventional models of particle and nuclear physics. Electron beams may glance off silver atoms in a metal foil. They may, as Sternglass himself had studied, knock other electrons out of a silver atom. However, the electrons in Sternglass' tube, propelled by just 35,000 Volts, were moving far too slowly to yield any nuclear reactions. Einstein pointed out to Sternglass in a letter dated just four days later, "In order to form a neutron, an electron is needed that has passed through 780,000 Volts."

A low-energy neutron source, Sternglass knew, could have dramatic implications. In 1951, the world's top neutron production factory was a billion-dollar plant at the Atomic Energy Commission's facilities in Hanford, Wash. But Sternglass seemed to be producing neutrons with an experimental setup costing just thousands of dollars. Once produced, these free neutrons could act as a kind of "philosopher's stone." They could, for example, create plutonium atoms from uranium. In fact they could theoretically transmute any element in the universe.

Neutron transmutation could in principle produce precious metals—the wild dream of medieval alchemists. But the cost to do so would be prohibitive. Today, though, a different and more alluring goal beckons: clean energy. The result of a transmutation would often be an unstable atom, fated to decay. In doing so, it would emit an energetic electron or photon. If this energetic particle could be captured, it might be transformed to heat—and usable energy.

In 1951, Sternglass recorded only preliminary thoughts about applications for his apparent discovery. "What I found [might] be of great interest," Sternglass wrote in his unpublished lab notebook. "One would have a ridiculously simple neutron formation process—which might even be used in atomic energy applications."

Whatever the future held, Sternglass was ecstatic. Halfway through the first night's data collection, he called his wife, and the Cornell physics professor who built his experiment's X-ray tube, Lyman Parratt. Once he got home, he also called Morrison, who said he doubted that low-energy neutrons could have been involved. So throughout the rest of July, Sternglass refined his experiment and continued to collect data. He revamped the gas pump system in his tube, re-ran part of his experiment at the bottom of a salt mine to exclude cosmic rays, and studied alternate theories. Everything pointed to neutrons. The scientific literature, too, seemed to support him. J.J. Thomson—Nobel Prize-winning discoverer of the electron—had reported a similar finding in 1914. "He observed a radiation emitted from platinum," Sternglass wrote in his notebook, "...which I now believe is beta emission under the influence of neutron bombardment!"

Interest in Sternglass' result in the Cornell physics department was mixed with scandal. One faculty member told him that he'd heard rumors that Sternglass was faking his data. Later in the fall, Sternglass recorded another blunt exchange. “Talking to Prof. ––– yesterday made me feel rather upset,” Sternglass wrote. “He said that ‘even granted that there might be some effect noticeable in my data, he would not be interested in it.’ … And that there were many ‘queer experiments’ in the history of physics which no one could explain… It struck me that this was certainly a strange scientific attitude,” Sternglass continued.

Einstein, though, was more thoughtful. In just one brief paragraph in a letter dated Aug. 30, 1951, Einstein wrote two sentences that were as insightful as any idea he had formulated in his postwar years at Princeton. “Perhaps reactions occur in which multiple electrons simultaneously transfer energy to *one* proton,” Einstein wrote (his emphasis). “According to quantum theory, this is somewhat conceivable, although not probable.” What Einstein had suggested to Sternglass involved ensembles of electrons behaving collectively as one entity with shared attributes. Think of it as a group of kids pooling their pocket change to buy one candy bar. Today everything from superconductors to lasers relies on the collective behavior of electrons, but in the 1950s this was largely a distant and theoretical prospect.

Einstein had made a characteristically brilliant leap. But neither he nor Sternglass nor indeed any contemporaries had either the technology or the theoretical framework to make sense of Sternglass’ data. Neither his data, nor Einstein’s supposition, were published. Sternglass already had a thesis subject: secondary electron emission, a topic that ruffled no feathers. As Sternglass describes it in *Before the Big Bang*, he did rerun his neutron creation experiment nine years later when he was working at Westinghouse Research Laboratories. By then, however, Einstein had died. And using Westinghouse’s lab facilities, Sternglass couldn’t replicate his Cornell data (though it is worth pointing out that a colleague of his at the Naval Ordnance Laboratory had been able to reproduce his data in 1953). “To this day, just exactly how neutrons can be formed at much lower energies than expected in the complex environment of a gas-discharge tube remains a mystery,” Sternglass concludes in his 1997 book.

That could have been the end of the story. But, in an unexpected convergence, a completely independent line of research begun 25 years ago has resurrected interest in Sternglass’ low-energy neutrons. In 1989, two chemists at the University of Utah caused a worldwide media storm when they announced at a press conference that they’d invented a method of sparking nuclear fusion in a simple, tabletop apparatus. Stanley Pons and Martin Fleischmann had found that running electric current through a specially prepared palladium electrode immersed in heavy water produced copious amounts of heat, more than what would be expected from a chemical reaction. “Cold fusion,” the headlines blared.

But physicists then responded much as they do today: Cold fusion is simply a non-starter. There was none of the radioactivity, gamma rays, or high-energy neutrons that are expected to accompany a fusion reaction. What, then, could explain the data? As cold fusion became a pariah field, a few made the connection to low-energy neutrons. In May of 1989, just one month after Pons and Fleischmann published their data, someone named Larry A. Hull wrote a letter to the editor of *Chemical & Engineering News* speculating that they may have been observing not fusion but transmutation, brought about by the same low-energy neutrons that Sternglass had claimed to observe.

This interpretation lay on the periphery of the cold fusion research community (which was itself on the periphery of the broader scientific community) for more than a decade. It was only in 2006, with the publication of a landmark paper in the *European Journal of Physics C*, that neutron-induced transmutations, as something distinct from cold fusion, began to emerge as a viable theory. The paper predicts that electrons on a metal surface coated with hydrogen, deuterium, or tritium atoms can behave collectively (as Einstein had predicted) when driven by an oscillating electromagnetic field at a particular frequency. This collective behavior can give them enough energy to combine with the hydrogen, deuterium, or tritium to make neutrons.

The paper goes on to say that the resulting neutrons travel very slowly—slow enough, in fact, to get gobbled up by a nearby atom before they can even leave the microscopic vicinity of their birthplace. The atom then becomes unstable and might burp out radioactive decay byproducts like a gamma ray or energetic electron. A separate paper by the same authors calculates that microscopic surfaces of electrodes, like those that tend to produce low-energy neutrons, are efficient

ILLUSTRATION BY GERARD DUBOIS

absorbers of radioactive gamma rays. So radioactive decay can be transformed into a bath of innocuous heat. And of course heat energy can readily be converted into electricity.

The above picture does not involve fusion, which would require blazing energies on the scale of the so-called "strong force" which holds together neutrons and protons. Instead, it requires lower energies on the scale of the nuclear weak force, which mediates the capture of an electron by a proton.

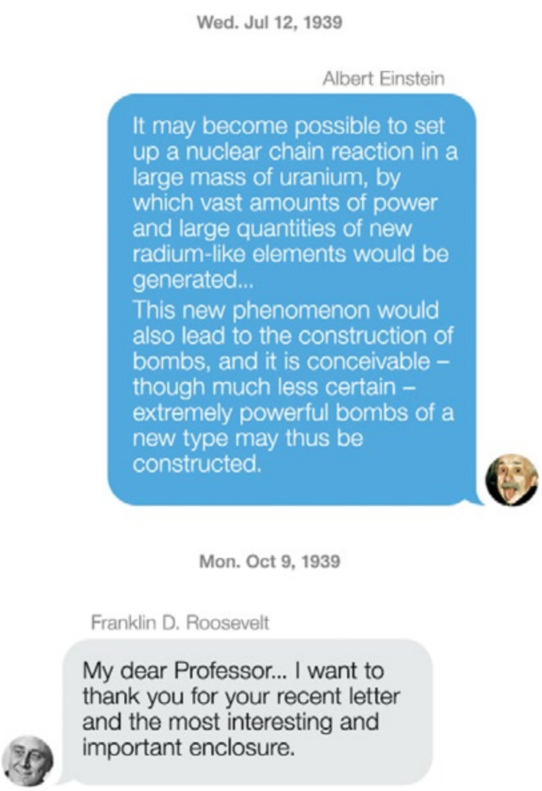
The papers' authors—Northeastern University physics professor Allan Widom and Chicago-based energy industry consultant Lewis Larsen—developed their ideas independently of the unpublished Sternglass-Einstein work. Although both Widom and Larsen declined interview requests for this story, both have separately noted that it was only after their paper's publication that they ran across Sternglass's work and Einstein's interpretation. "What is truly mind boggling about this is that Einstein simply *looked* at Sternglass' data and then immediately realized that the observed neutron production must involve some sort of many-body collective effects with electrons," Larsen writes.

The Widom-Larsen papers harkened what can only be described as a minor renaissance in research into low-energy nuclear reactions (the term "cold fusion" having been dropped). In March of 2012, the European Organization for Nuclear Research (CERN), which runs the world's most powerful particle collider, held its first colloquium related to the Pons-Fleischmann data since 1989. In November of 2012, the American Nuclear Society held a breakout session about low-energy nuclear reactions at their winter meeting in San Diego. And NASA's Langley Research Center in Hampton, Va., has devised a series of experiments to test the Widom-Larsen theory.

Researchers are making clear that there is a growing body of experimental data that is consistent with the theory. Francesco Celani, researcher at the Italian Institute of Nuclear Physics, described to his CERN audience 20 experiments after Pons and Fleischmann that have also yielded inexplicable quantities of heat—though they were only sporadically repeatable. Yogendra Srivastava, professor of physics at the University of Perugia in Italy, explained at the same colloquium that hundreds of papers have been published about

Return to Sender

Years before Sternglass paid Einstein a visit, a couple of other physicists stopped by to see him at his cottage at Peconic Bay in Long Island. They discussed the possibility of atomic bombs, and the rumor that research in Germany involved uranium. They wrote a letter, signed by Einstein, to President Franklin Roosevelt.



Roosevelt went on to convene meetings on the possibility. In 1942, the Manhattan Project to develop an atomic bomb launched. Einstein was not involved in the Project, and almost a decade later, his comment to a reporter in a 1947 issue of *Newsweek* hinted at regret.

"Had I known that the Germans would not succeed in developing an atomic bomb, I would have done nothing."

thin wires that, when overloaded with electric current, explode—and, according to some experiments, produce neutrons. He described how any potential technology based on low-energy neutron production would be the first exploitation by mankind of the weak force, one of the four fundamental forces of nature. As Joseph Zawodny, a senior research scientist at NASA Langley, put it, "I can't imagine that there's a whole force of nature out there, one of just a few, that is boring, disinteresting, and not of any use."

At the same November American Nuclear Society meeting, Tadahiko Iwamura, from Mitsubishi Heavy Industries in Japan, described Mitsubishi's experiments on neutron-induced transmutation. Iwamura said his lab had watched while the radioactive element cesium was transformed into a less-harmful heavier element, praseodymium, when deuterium had been forced to flow past it. Cesium is commonly found in nuclear waste. During the question and answer period, Iwamura surprised the audience with the admission that other scientists at Toyota had independently confirmed Mitsubishi's transmutation data.

But the research faces a strong headwind of public and scientific skepticism. This is partly due to the continued activity of a much larger group of present-day cold fusioneers, who have failed to advance any tenable theory for tabletop nuclear fusion. "The distinction between the real science and the pseudoscience is not widely known yet," says Steven Krivit, editor of *New Energy Times*, a newsletter devoted to the underground scientific movement kicked off by the Pons-Fleischmann experiments. Even NASA has taken its share of flak. In 2011, the watchdog website NASA Watch headlined a story with the title "Why is NASA Langley Wasting Time on Cold Fusion Research?"—a title which ignores the distinction between (strong force) fusion and (weak force) low-energy nuclear reactions.

The field is also plagued by the variability of experimental data, says NASA Langley chief scientist Dennis Bushnell. Sternglass' inability to reproduce his Cornell data at Westinghouse was a first glimpse of this. Bushnell points out that according to the Widom-Larsen theory, inciting a proton to capture an electron requires extremely strong local electric fields, up to 100 billion volts per meter. "And there are several ways to get that," Bushnell says. "One way is to up the voltage. The other way is to reduce the meters." If transmutation does indeed depend on nanoscale features like dust grains, cracks, or impurities—features with "reduced meters"—then experimentalists must solve the difficult experimental challenge of controlling their materials at these scales.

Zawodny, while making clear that transmutation only holds a provisional promise, says that the applications to energy generation cannot be ignored. "Low-energy nuclear reactions still can't boil a cup of tea," he says. "But if this played out in the most optimal way, and this replaced all forms of energy generation, you're talking about $6 trillion or more per year of market," he says. "If this is real, the impact is so huge and the applications to our current problems and the ability to solve them quickly are so obvious that we cannot not do this."

The researcher who agrees with Zawodny, and is intent on pursuing this controversial but potentially important line of research, will appreciate Einstein's parting advice to Sternglass. In March 1954, thirteen months before Einstein's death, Sternglass sent his mentor a copy of his latest publication on secondary electron emission as well as a 75th birthday card. In what would be his last letter to Sternglass, Einstein sent a printed thank you note. On the back of the card was a handwritten response consisting of just two words.

"Be stubborn," Einstein said.

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Albert Einstein's letters (written in German) to Ernest Sternglass were translated into English for this article by Hans-Jochen Trost.

For more information on the Widom-Larsen theory and low-energy nuclear reactions, see the newsletter *New Energy Times*.

Thanks to Ephraim Fischbach for his expertise on this article's technical aspects.


You just won
$100,000

Kellogg's

The last wholesome fantasy of the middle-school boy

BY B.J. NOVAK

IT WASN'T LIKE THIS boy to throw a tantrum in the cereal aisle of the supermarket, and it wasn't like his mother to give in to one, but here they were, for some reason, both making an exception.

"Okay," she said, and threw the box deep into the far corner of the main part of the shopping cart. "Okay. Don't let your father see it."

The family never bought sugar cereals and never bought name-brand cereals, so this split-second sight of his mother's wrist flicking an official name-brand sugar cereal into the cart was something he had to keep replaying in his head for the next several minutes until he was literally dizzy on the image of the impossible. The sensation of seeing and reseeing that wrist snap was something he couldn't make sense of, something that would be best described by words he didn't know yet: surreal, pornographic.

ILLUSTRATIONS BY LEO ESPINOSA

The boy kept an even pace with the white-dirt-frosted black wheels so he could stare uninterrupted at the creature that he and his mother had captured. Yes: There in the cart, after all these years, was Tony the Tiger, caged at last. And Tony the Tiger promised even more fun ahead: In a bright blast of words spilling from his sportive expression, Tony the Tiger explained that the box on which he was emblazoned contained not just name-brand sugar cereal—as if that weren't enough—but also a miniature treasure chest, and—as if *that* weren't enough—inside the treasure chest was a secret code, and—as if *that* weren't enough!—the code could possibly lead to a cash prize of *one hundred thousand dollars.*

(When the boy looked closer, as the box rode across the checkout belt toward the outside world, on the way to the arguably more humane captivity of a kitchen cabinet, he noticed that Tony and the text were technically separate, with no speech bubble connecting them: Tony the Tiger wasn't saying that; he was just next to those words. Somehow, this felt like it gave the promise a touch less credibility, even though, when the boy thought about it years later, it would occur to him that this should probably have given it more. It didn't matter, though: Everything, even this late-breaking potential scandal, rang with the drama of a new name-brand world he knew he never wanted to leave.)

Usually, when the boy got home from grocery shopping, he helped his mother unpack the bags in the kitchen, mainly by reveling in how rich their family seemed to be for this one moment each week and wondering which item he would honor by opening it first. But this time, the boy ran right to his room with the cereal box so that he could keep his word to hide it from his father, who found both the boy and the box only minutes later, drawn by the sobs to his bedroom, where the boy was discovered crying over a torn-apart box of Frosted Flakes.

"I thought we didn't buy this kind of cereal," said the boy's father, crouching down to look directly at Tony the Tiger, eyeing him as one would an enemy and an equal.

"If you have the right secret code in the box in the treasure chest," explained the boy, swallowing mucus, "you win a hundred thousand dollars. We'd be rich."

"I'll make you a deal," said the boy's father.

The boy's father stood up and pulled a hardcover dictionary from the shelf above the boy's bed, the frayed sweater he always wore on non-teaching days riding up as he reached.

"If you can guess the word I'm thinking of on this page, I will give you a hundred thousand dollars."

The boy stopped crying and guessed. He guessed wrong. This time the boy was too confused by this whole whatever-it-was to cry. "What would you have done if I got it right?" "I have no idea," said his father, with a smile-like expression the boy had never seen before. "But you didn't." The boy didn't quite understand how this lesson had worked—he didn't have the words for this yet, either. There was something odd and cool about his father's introduction of this consolation contest, something that he would later be able to describe as something like wryness; some offbeat calm about this presentation of a paradoxical idea, the promise of a possibility that couldn't possibly be kept. For now, while the boy didn't yet have the words to explain the feeling, he could feel it, and he liked it, and he wanted to be a part of it. So he accepted this as the conclusion of the story of the cereal-box contest.

But not for long.

The next day the boy ran to the supermarket with all the money he had the second the school bell rang;

bought five boxes of Frosted Flakes and another three of Corn Flakes with the same prize offer on the box; and ran back to school in time to catch his bus.

He felt especially adult to be riding the bus with grocery bags and desperately hoped that someone would ask him why.

"Why are you carrying grocery bags?" one girl finally asked. "None of your business."

The boy got home and started ripping up the boxes, starting with Corn Flakes, so that the Frosted Flakes, which he actually liked, would stay fresher a few seconds longer.

On the first box of Corn Flakes, he lost. On the second box of Corn Flakes, he won the $100,000 prize.

On the first box of Corn Flakes, he lost. On the second box of Corn Flakes, he won the $100,000 prize.

The boy checked the other boxes just in case he won anything else. He didn't. That was fine. One $100,000 prize was still a good day's work.

The boy called a family meeting, his first.

"First, I have a confession to make," said the boy. "I know we don't buy sugar cereals or brand-name cereals. But I went to the grocery store by myself today, and I bought more boxes of Corn Flakes and Frosted Flakes so I could enter that contest again. So I broke two rules. I'm sorry."

"Thank you," said the boy's mother.

"We understand," said the boy's father, with something calm and ironic in his tone again. What was that? Wryness, again? "Thank you for your honesty."

"Okay, good," said the boy. "Now the good news: I won the contest. We're rich!" This story is about to take a more personal turn, and I am starting to feel less comfortable that I am telling it the way that I am. So let me come clean on a couple of things: I am the boy in the story, and this is the story of how I found out my father was not my father.

"Let me see the box," he said quietly. I handed it to him. He looked at it. "Now let me see another box," he said. "A losing box." "Which losing box?" "Any of them." "There are seven—" "Any fucking box," he said quietly. "Any box. All of them, just one—any of them." I walked over with all the boxes. He looked at two and then put the rest back down. "Go to your room for a few minutes. Your mother and I are going to discuss this."

"There are values," my father said an hour later to begin the unprecedented second family meeting of the day, "that some people have—that many people have—that most people have. That we *understand*—that we *respect*, definitely—that are the prevailing values of the day, even, and we respect that, too, on its own terms, but. *But.* Respecting a value doesn't necessarily mean sharing that value—often, but not always—only sometimes, anyway. For your mother and I . . . We in this household . . . . That's what we believe."

I had no idea what he was talking about. My mother looked like she knew what he was supposed to be talking about, but didn't like the way he was saying it.

"We are not going to claim the prize," said my mother.

Now I understood why my father had answered in such a nonsensical way: What he was trying to say made no sense.

"Why?"

"Because it's based on actions that we don't allow in this household," my mother said. "It's the result of broken rules."

"But I already broke the rule, and you forgave me," I said. "It doesn't work like that," said my mother. "Why don't you punish me for that," I said, "something fair, like grounding me, and then I'll keep the hundred thousand dollars. You wouldn't fine me a hundred thousand dollars just for going to the store when I wasn't allowed to, right? You'd ground me, right? So just ground me. Okay?"

"But everything that would follow would be based on breaking that rule," said my father. "So any change in our lives—and there would be a great many—would be following from a corrupt core, from a foundation of values we didn't believe in. Do you understand?"

"This is a test, in a way," said my mother. "A test of fate."

"Yes, except there's no such thing as fate, there are only consequences of previous actions, and coincidences, which are the consequences of factors and decisions which are too many and too minute to be aware of—"

"Okay," said my mother. "Okay, stop. In any case, it's a test of our values."

"How about this," I offered. "You put all the money in a college fund for me. I'm not even allowed to touch it until I get to college. And then, it's only to pay for college."

I stared at them, daring them to turn down a prospect as joyless as this one. If I won a hundred thousand dollars and it all went into a college fund, would it still be the greatest single letdown of my life? Yes. I had no interest in college; I planned to be a professional wrestler. But at this point I just needed to find out if this free-falling disappointment even had a floor.

"No," said my mother.

"That would still be basing everything on something that isn't our value system," said my father. "In terms of college, if you work hard, there are still plenty of ways to earn scholarships or find alternative paths toward a good education without a lot of money."

"I thought you said all of higher education was corrupt and based only on money," I said.

My mother looked at my father.

"I said that in a heated moment, in the midst of a stressful tenure . . . No, there . . . there are definitely ways . . ."

I no longer understood my parents.

"Can I at least keep the sugar cereals?" I asked.

They looked at each other.

"Yes," said my mother.

"*All* of them?"

They smiled, relieved to have this conversation end on the word "yes."

"Yes," they said.

"Okay," I said.

I had no interest in college; I planned to be a professional wrestler. But at this point I just needed to find out if this free-falling disappointment even had a floor.

It wasn't okay at all, and looking back, I think that question represented the birth—forced under high pressure at the age when a moment like this is bound to be born anyway—of my first pulse of truly sophisticated manipulation.

In that instant, it had suddenly come to me—the way I would imagine a melody suddenly comes to musicians—that if I were to ask that adorably missing-the-point question, I would appear to them like the fifth grader who would leave it at that, who would trust that his parents were always right, instead of the fifth grader who now knew, with certainty and for the first time, that his parents were wrong and that it was his destiny to use all the powers he had, including a calculated flash of the belovedly unpredictable kid logic of their only child, to set things right.

Tom Salzberg was a fifth grader who was old for our grade and acted it. We weren't exactly friends, but I considered us respectful acquaintances, and I had a sense he would know what to do with this information. I found him at his locker in the three minutes between homeroom and library and quickly told him everything.

"Mm-hmm," he said. As if this happening were one of many things like this he had to balance today. As if it had happened before. "Mm-hmm. Do you know where the ticket is?"

I told him as we walked into library that I was pretty sure I knew where it was in the house and that in any event I could find it. To show him how much I meant business I rushed through a recap of how I had hidden my motives behind the "can I keep the sugar cereal" story, which I thought would at least amuse him, but even this abridged version he seemed to find uninteresting, and by now he was sitting at the one library computer terminal that had internet, which I knew meant I was about to lose his attention for good. "If you can get it by Thursday," he said, eyes fixed on the computer monitor, "we have a half day then for teacher meetings. We'll be out at eleven-thirty. Battle Creek, Michigan, is an hour and a half away. That's where Kellogg's headquarters is." He tilted the screen toward me and revealed a picture of an immense, futuristic, fortress of a building—the last wholesome fantasy of a middle-school boy. "Tell your parents you have a soccer game after school and my parents are giving you a ride home after dinner. Tell them that we're having pizza." I didn't play soccer or eat pizza, but I accepted this story unedited, and so did my mother when I got home from school that afternoon.

There was then, in our house, an unused staircase behind the kitchen that my mother had long ago decided was too steep to be safe. Instead, it had been repurposed as a mostly empty diagonal closet where my parents kept things like tax returns and unwrapped presents. It was closed off by an unlocked door on both sides, and while I had glanced quickly inside a handful of times over the years whenever one of the doors had somehow slightly opened, I had never actually personally opened the door, for fear of accidentally ruining my own birthday or the still-ambiguous-by-mutual-agreement myth of Santa Claus.

Separately, I had, two years earlier, toward the beginning of third grade, realized in an epiphany over an inspiringly decadent breakfast-for-dinner that midnight was not actually the middle of the night: If the night was something that started at 8:00 p.m. and ended at 7:00 a.m., as I knew it to be, then the middle of the night was actually 1:30 a.m. My parents happily confirmed this for me. Although my bedtimes had shifted in the years since, I still believed with stubborn auto-loyalty that 1:30 remained the official unofficial middle of the night.

That night, I stared at my clock until it said 1:29. Then I took a full minute to step out of bed, wearing both socks and slippers, determined to take no chances, and shuffled out of my room on the heels of my feet, rather than tiptoe, which I had noted long ago was actually more squeaky than "tip-heel," my own invention as far as I knew. I stepped out and opened the door that I had walked by thousands of times, and then for the first time I took one step after another down the staircase, until I was alone amid the clutter and mystery, unarmed except for a small emergency flashlight that cast a small square light into the cold diagonal corridor, where everything was more or less the color of manila.

On top of a video game I had asked for a long time ago was a dust-free white envelope. I picked it up. It wasn't even licked shut. Inside was the winning strip of cardboard from the Corn Flakes box. I put it in my pajama-pants pocket and returned the envelope to where it was. I slipped back up the stairs, closed the staircase door, put the cardboard code under my pillow, and waited for 7:30, never closing my eyes except to blink, constantly checking to make sure that the code hadn't evaporated.

The dictionary that had been used for the now-even-more-irrelevant contest rematch was still on my dresser. Out of an instinct I didn't have the word to describe yet—irony? panache?—I put the winning code in the middle of that dictionary, put the dictionary in my backpack, and took it to school.

At lunch, I found Tom Salzberg in the cafeteria and showed him the scrap of cardboard.

Tom stared at the numerical code and the YOU ARE A WINNER message right below it for a long time. He had been convinced the whole thing was real when he had only my word to go on; now, staring at the actual evidence, he seemed somehow less sure about it all.

"50-50," he finally said.

"No," I said. I hadn't expected to pay him anything. "80-20," I said.

He squinted in consideration for one second, then made a face identical to the Robert De Niro face that had failed to win him placement in the class talent show and shook my hand.

"I'll buy the bus tickets with my mom's credit card, and then I'm going to call us a taxi to take us to the Greyhound station." I had never been in a taxi before but didn't feel like letting him know that.

"Shotgun," I said.

The Battle Creek, Michigan, headquarters of Kellogg's looks like a spaceship built to look like a pyramid that was then hastily converted into a public library during a period of intergalactic peace. It looks exactly as you would hope it would look. As fun as it is to try to describe, I still recommend you look it up. It's really something, and it will help you imagine how it felt to be a pair of eleven-year-old boys walking up to it, secretly carrying a secret code worth $100,000 in a backpack.

We walked through the glass doors as if we had a business meeting ourselves, as businessmen and businesswomen streamed in and out of the building around us, none of them questioning our right to be there. When we finally reached the all-glass reception desk inside, I realized I didn't know what to say.

Tom did.

"Prize Department, please," said Tom.

"I'm sorry, how can I help you two?" said the reassuringly plain-looking woman at the desk, a woman with brown hair and plastic glasses who looked like she could have been one of our teachers.

"Prize Department—Sweepstakes Prize Subdivision," said Tom with even more authority. "Also check under Giveaways—Secret Code Redemption."

"Do you have a name, or a person you're looking for?" she said. I took the winning code out of my backpack and—holding it tight with two hands, not trusting even this palpably kind woman, our one ally so far—held it for her to see, but not touch.

"Oh my. Congratulations! How exciting. Are you two brothers?"

"No way," said Tom. "Prize Department, please."

"It's my ticket," I said. "He's just my friend."

"What's your name?" the woman asked. I gave her a copy of my school ID. She paused as she read the name and looked at me again.

"Let me just copy this, and you wait here."

We sat on the stiff leather couch for five minutes until an extremely tall, extremely confident, very handsome, and athletic-looking man in a notably soft-looking suit walked up to us and smiled. "Congratulations. Which of you is the winner?" he asked, but he was staring at me the whole time.

"I am," I said.

"Congratulations," he said again, extending a hand. I stood up so I could shake his hand appropriately, and he shook it so hard it hurt. "Come to my office and let's discuss this."

Tom stood up, too.

"Just the contest winner," said the man.

Tom kept standing. "It's a trap," he blurted, his voice breaking, exactly as our books on puberty had warned us might happen but had never happened so far. "It's a trap!"

"It's not a trap," said the man.

"What department are you in?" asked Tom. "Can we see some ID?"

"I'm Executive Vice-Chairman of the Kellogg's corporation," said the man in the suit, "and I don't need to show ID here."

Tom sat down.

The man gestured toward the long hallway ahead of us—*after you,* the gesture said—and even though I didn't know where we were going, he let me lead the way, until we got to the elevator and he pressed the top button, and he took it from there.

The office was huge, and quiet. Windows looked out over all of Michigan, to Grand Rapids and beyond; there were many windows, or more accurately so much window, that the room was very bright even with none of the lights on. Little toys were neatly lined up across his long windowsill—a tiny basketball, a tiny pistol, a tiny lemon—each of them sitting on top of a bronze label on a plaque. Also on the walls were about a half dozen framed, colorful drawings, each signed by many children, thanking him for their "super" and "great" and "super great" and "wonderful" experiences on field trips.

"You have an unusual last name," the man said, and then said all five syllables of it correctly.

I said yes, I had never met anyone else with it, and it seemed that no one could ever spell or pronounce it. I was impressed he had gotten it right.

He asked more easy and straightforward questions: who my parents were and what they did; what town I was from; whether I had brothers or sisters. It was a great relief, in the midst of such an intimidating situation and environment, to be asked questions I could answer without even trying to think. I kept talking, letting each answer of mine go longer than the last, which led him to even more questions. How's school? Public, private? Easy, hard? Sports? Baseball, soccer? Tigers, Red Wings? Video games? Friends, best friends, bullies, girls? What do you want to be when you grow up? How do you get along with your parents? Do they often buy Kellogg's products?

Before long everything tumbled out: how my parents had strict policies against both sugar cereals and name-brand cereals, even the healthy ones; how I had felt drawn to the box in the store anyway; how I had, to my embarrassment now, cried when I lost, which I knew I was too old to do; that very weird follow-up contest that my father had set up for me with the dictionary and the expression he made that I didn't know how to describe; how I had gone back to the store by myself after school; the bizarre and nonsensical things my parents had said about why it was somehow against our values to redeem the prize; how strange it had felt to be sure for the first time that my parents were wrong, and how frustrated and confused and angry it had made me; the staircase, Tom, 80-20, how the taxi driver didn't want to let me sit in the front seat for some reason.

After I said everything, he stared at me for a second and paused.

"I can't give you the prize."

My mind first went to Tom, warning me that this was a trap.

"Regulations prohibit families of Kellogg's employees from participating in this contest or claiming a prize," he said. Then he smiled, and there was—the only time I've ever seen this in real life, and a phrase I had never been able to quite understand until now—a glint in this person's eyes.

"And I'm your father."

"I'm going to tell you a story. And then you tell me what you want to do.

"Twelve years ago, I was a visiting lecturer at the Steven M. Ross School of Business at the University of Michigan in Ann Arbor. I was twenty-nine years old at the time. I was the youngest senior vice president in the history of Kellogg's. I had called up the school myself and offered up my services as a visiting lecturer for one semester. I explained how it was important to give something back to the community, be a role model, to whom much is given much is expected, all that. But that wasn't it at all. By the way, if I never see you again, and end up teaching nothing else to you—that's the one thing I want you to have learned from me. People—even good, impressive people—always want something simple and unimpressive. Everything good and impressive that they do in their lives is a result of the impressive path they take to get what they want—not a result of wanting an impressive thing. It's what brought me here. It's what brought you here.

"I was really giving myself one semester—that's only three months—to find a wife. Someone genuine and beautiful and interesting, and someone outside the circles in which I lived. This wasn't much time, but I was an overachiever, and confident, and I was used to accomplishing things in very set periods of time.

"On the first day of the first class, I saw her. Pale, freckles, hair in a messy, frizzy light poof. T-shirt. Beautiful. The reason I was there—I knew that right away. Last seat of the last row. She looked like she didn't want to be there, and she didn't: It turned out she was a French literature major, and this class was the economics requirement that she had delayed until her final semester because she hated anything that had to do with money. So I wasn't in the best position to impress her. Which I liked, too.

"There were twenty students in the class, so I was able to institute fifteen-minute meetings with each student individually each week. I scheduled hers last, on Friday afternoons. I was even more taken upon second sight than I was at first. She was brilliant and sarcastic; inner fire, light touch, certain of her values, which I had a sense were better than mine and which I wanted to learn from. I was sold.

"Now, there were two pretty considerable obstacles in my path. The woman was about to become engaged to the only man she had ever dated, her boyfriend of five years, a man she told me she loved definitively. And in addition to that, she went out of her way to make it clear that, separately, she had absolutely no attraction to or interest in me as person. She emphasized these things a little gratuitously, in fact." He laughed.

"I continued to meet each of the students once a week for the twelve weeks of the class, just to justify seeing this woman. Every week when the two of us sat down, I started with the same question: 'How's your boyfriend?' 'Couldn't be better' was her answer every time, and then we would run out the rest of the fifteen minutes in a conversation about basic economics that neither of us had any interest in. This was nine weeks. The tenth week, I didn't ask my opening question, and we just talked about economics the whole time. The eleventh week, she brought up her boyfriend right away and walked me through her doubts about the relationship for the entirety of the session, which this time ran almost an hour.

"On the final week of the semester, she told me that she was questioning everything in her life, that her relationship had in fact been over for some time, and that she didn't know what to do. We continued to talk about this for the rest of the afternoon, over dinner that night, and the next morning over a balanced breakfast.

"She stopped returning my phone calls immediately and moved out of her dormitory. After several weeks, I tracked down her parents' residence through a student directory to which I was not supposed to have access, and she picked up the phone in another room and delivered all the following news in the space of about a minute: She was pregnant, she was getting married within the month, and it had taken her brief time with me to make her realize that her boyfriend was and would always be the love of her life. I was never to contact her again. They were in love, she said.

"I was in love, too. I suggested that I might confront her fiancé and tell him everything, including my theories as to the timing of the pregnancy. She said she had already told him everything, that they were determined to raise the child as theirs, and that I was not welcome in their lives in any way. She raised the prospect of a restraining order against me and, more chillingly, whatever reputation-ruining accusations would

We continued to talk about this for the rest of the afternoon, over dinner that night, and the next morning over a balanced breakfast.

be necessary for her to obtain one.

"But it was actually her passion that gave me pause, more than her threats. Because while I knew I was in love, I could see that my love wasn't as big as their love, and I decided that was reason enough for me to retreat. That's the part that I've questioned since, and I'll tell you why in a moment.

"Now, as you can see"—he leaned back and gestured around the office and to the immense window behind him—"I have an excellent career and, all in all, an excellent life. But I was right to try to act fast in that three-month semester: In the dozen years since, I have not come close to finding a person I've wanted to share that life with. Not anywhere close. So I share my life with no one. I am happy, make no mistake. The life I live alone is a great one. But I do wish I had a family. It's the rare goal that has eluded me so far.

"Your parents love each other very much. From the information I know, I wouldn't try to argue that they are anything less than one of the great love stories of our age. That they would sacrifice everything—from money, to truth, to enjoyment of the universally acknowledged finest breakfast cereals in America—just to stay loyal to each other, and to the family they were determined to have together? It's something. It really is.

"But I ask you—and I can tell you're smart enough to grapple with a real question: Is love such a strong force that it needs to be obeyed by the people who lie outside it?

"Think about this, specifically. The love of your mother for the man you know as your father is the ultimate force known to those experiencing it. Fair. Fine. But to anyone else? To me? To you? Is it selfish to impose the consequences of your love—infinite only to you—on the lives of others? If it means denying someone something as big as the life he was meant to have?"

He pointed to me with the same hand that had gestured out the window. "What sneakers do you wear? What musical instruments can you play? What languages do you speak? Have you ever been to the Olympics? Read a book in a café in Barcelona? Pretended to read a book in a café in Barcelona? What colleges does it not even occur to you to wonder about?"

I asked him if he thought, like my mother did, that this was a test of fate.

"It certainly feels like fate in this moment, doesn't it?" he said, smiling. "But if you really think about it, it's actually more magical, more special—more faithful, even, in the bigger way, and to say nothing of more true—to not believe in fate.

"Fate, to me, simply means that all the billions of microscopic actions we can't calculate lead to consequences that feel right because they *are* right. They fit, they follow. We can't see and understand all the causes behind everything, but I think it's more magical to accept that they're there than it is to believe that they're not, and that something called 'fate' is filling all that space instead.

"Whatever you call it, fate, not-fate—and I usually do just call this fate, by the way, just because it's simpler, it sounds more optimistic, more true to the spirit of what I mean—it's better branding—but whatever it was, something in your nature drew you to that cereal box in the store. The promise of bigger things, brighter colors, better tastes. Curiosity. Chance. Fun. The promise of money. Hope. The feeling of being a part of the national experience—populism, you could call it; patriotism, you could call it. Then you were told that this cereal wasn't something you could have—and you broke a rule. You broke several rules, and you never break rules—that's how loud this called to you. I don't believe it was fate that did this, to speak honestly, no. I believe it was bigger than that. Grander than that. Because these are drives that are in your blood—just the way that they're in mine. If you were someone else's son, these drives wouldn't be in you, and you wouldn't have been drawn to that box the way you were. These drives are not, with all due respect, in the blood of a philosophy professor who would say that he doesn't believe in sugar cereals on principle. And I actually mean that phrase—'with all due respect'—because I *do* respect it. It's just not me. And it's sure as hell not you. Because when you won the prize and then were told the prize wasn't something you could have, that didn't work for you. The exact same way it wouldn't have worked for me. Something in your nature was telling you that the rules of your childhood home weren't the rules of your life anymore. You broke those rules and then kept breaking them, because you wouldn't let anything stand in between you and what you knew you were destined to have. You followed an impulse. A chain of impulses. Impulses that were there for a reason. And now, here you are.

"Your parents lied, too. They wouldn't allow popular cereals into the house not because of the price or because they aren't healthy—I could give you a stack of nutritional information comparing our cereals with the homemade pancakes you told me you eat several times a week—but because of the personal associations for them. And they wouldn't let you claim your prize because they knew it would lead you to learn the truth. They knew that all sweepstakes of this kind are never applicable for family members of company employees and that even the most perfunctory background check by the company, especially with a last name as distinct as yours—even Beverly, at the desk, whom I've known for twenty years, noticed it—would lead someone in some department to take notice and allow us—force us, by federal law—to not only deny you the prize, but also blow up this family mythology they already sacrificed so much in order to invent and protect. Look, I can't blame them. You're an extraordinary young person.

"So, as I've said, I can't offer you the prize. But I can offer you something else."

A part of me wondered if he was going to pull a dictionary down from the wall.

"You can be my son."

He handed me a business card.

"Think it over. Think about who you are and how you see yourself going forward. And if it makes sense to you, give me a call. Don't let your mother see this, of course."

He shook my hand again, just as hard.

Tom leapt up off the couch when he saw me cross back into the lobby.

"What happened? How did it go?"

"It's called the Promotions Department, idiot," I said. "Not the Prize Department."

On the bus ride back to Grand Rapids, I stared out the window for the hour and a half.

I imagined what Michigan would look like—or what it would feel like to look out at Michigan—if I were the kid of the executive, and then if I were just the kid of my family. The two feelings felt very different.

I liked them both.

I liked the feeling of being able to switch back and forth in my mind, too.

I wished the bus ride were longer.

"How was Tom's? How was pizza?"

I forgot all about the lie I had told my mother, that I was having pizza at Tom's. It seemed quaint, and cozy, and sad.

"It was good."

"What kind did you get?"

"Pineapple."

"Yum! You have room for dessert?"

"Yes," I said. "Why?"

"What do you mean, 'why'?" My mother laughed. "In case you want to have dessert with us!" I looked over into the kitchen and saw my dad in his sweater, making a pot of mint tea the way he always did after dinner.

I loved my parents so much.

"Go upstairs and put your things away," said my mother. "It'll be ready in about five. Ice cream sundaes."

I went up to my room and took the business card out of my pocket. I noticed that it was now completely crumpled from how tightly I must have held it on the bus ride back.

I put the business card in the dictionary and came down for dessert.

My father set out three teacups and three ice cream bowls.

"Would you like some tea?"

"Yes, please," I said. "Thank you."

"It'll go well with the ice cream," said my mother. "Hot and cold."

I noticed a tub of frozen yogurt on the table.

"Is there ice cream?"

"This is the ice cream," said my father about the yogurt. "You put whipped cream and sauce on this, and all buried in a sundae, you don't know the difference."

"Okay," I said.

"Except there's no whipped cream," said my mother.

"Then why did you say it?" I asked.

"Hypothetically," he said.

"Okay," I said. "Can you pass the chocolate sauce?"

He handed me a fragile-looking glass bottle.

"We don't have chocolate sauce. This is agave syrup."

"I met my real father today," I said.

It wasn't that I didn't love my parents after that. I did, and I still do. We're still in touch.

But while I loved my family, I also knew that it wasn't who I was anymore. I was a name-brand kid, and I was meant to have a name-brand life.

Sometimes I wish I had learned everything earlier and that my real life could have started sooner. Other times, I'm glad that the first part of my life lasted as long as it did. It doesn't really matter, though. None of it could have been any different.

As for fate—or not-fate—I'm still not sure about it, but it's not something that keeps me up at night. I've lived it, and the people who think about that kind of thing can call it whatever they want.

BENJAMIN (B.J.) NOVAK is a writer and actor best known for his work on the Emmy Award-winning American television series *The Office,* on which he contributed as an actor, writer, director, and executive producer. He is also known for his appearances in films, such as *Inglourious Basterds* and *Saving Mr. Banks,* and for his standup comedy performances.

04

LIFE AND NATURE ARE full of the non-linear: everything from compound interest to the homeostasis that maintains your body temperature. But one of the most confounding non-linearities of all is the very unlikely. Let me explain why.

We intuitively understand 50/50 odds, like the chance of getting heads on a coin flip. And we can deal with the odds falling slightly, to 1 in 3, or 1 in 4. But when probabilities decrease far enough, our rational faculties can fail us. We find ourselves in a completely different world—one much harder to understand, but also one with truths to be discovered, both peculiar and necessary.

That's because there are marvels and wonders in the world of the unlikely, which have motivated scientists throughout the ages. And also severe challenges, even for the hardest of hard sciences. It is ultimately, as our stories show, a strange place to be.

Welcome to "The Unlikely."

—MS

"You don't have wonder. Wonder has you.
It grabs you by the lapels and shakes you."

LORRAINE DASTON
"Monsters, Marvels, and the Birth of Science" p. 44

The Unlikely

CHASING THE ODDS

Monsters, Marvels, and the Birth of Science

How the unlikely and unexplainable, strange and terrifying, spawned the age of science

BY STEVE PAULSON

ILLUSTRATIONS BY ELLEN WEINSTEIN

FINDING REGULARITY IN NATURE is the bread and butter of science. We know that reptiles lay eggs, while mammals bear live young; the Earth revolves around the sun every 365.25 days; electrons glom onto protons like bears onto honey. But what if some oddity seems to defy the laws of nature, like the platypus, an egg-laying mammal? What about an anomaly like a two-headed snake? Or a newborn baby who seems to be neither boy nor girl, but something in between?

These questions fascinated the founding fathers of science, and their attempts to explain such rarities and marvels helped shape modern science. In fact, nearly all the great philosophers and scientists of 17th-century Europe—Descartes, Newton, and Bacon notably among them—were obsessed with anomalies. If they couldn't explain the unlikely—a solar eclipse, a comet hurtling toward Earth, a narwhal tusk (was it a unicorn?)—all bets were off about an underlying explanation of nature.

Lorraine Daston, executive director of the Max Planck Institute for the History of Science in Berlin, has spent decades studying the emergence of modern science. One formative experience, she says, was a graduate-school seminar where she and fellow student Katharine Park noticed something strange. The philosophers they studied in their class on 17th-century metaphysics—Bacon, Hobbes, Leibniz, Locke—were obsessed with monstrous creatures. Their professor didn't care, nor did the other students, so Daston and Park carved out their own intellectual turf and wrote a landmark scholarly article about monsters. Years later they expanded the study and in 1998 published the monumental history, *Wonders and the Order of Nature, 1150-1750*.

Nautilus called on Daston to learn how the unlikely in nature, strange and unexplainable occurrences, were viewed at the dawn of science. In conversation Daston has a dazzling ability to leap across centuries, ranging over high culture and low, from Aristotle to *The National Enquirer*. Her insights into history illuminate the practice of science today. Daston spoke to *Nautilus* from Berlin.

Centuries ago, monsters seemed to embody the unlikely in nature. Why were early philosophers and scientists so fascinated by monsters?

They were interested in exceptions to the rule. One has to keep in mind that the 16th and 17th centuries were times of extraordinary religious, economic, and intellectual upheaval. From both the Far East and the New World, Europe was deluged by novelties of all kinds, such as animals that no one could possibly imagine, like birds of paradise and armadillos. On the religious front, monsters were seen as portents foretelling the apocalypse—the Second Coming. It was also a time of intellectual revolution. Copernicus published his book on the solar system in 1543. That same year, Andreas Vesalius published his book on the anatomy of the human body.

For European thinkers in the early 17th century, the scientific ground on which they stood was extremely unstable. Everything was changing, and people like Francis Bacon realized it was possible that the best minds over the last two millennia had been dead wrong about everything. He used monsters and other marvels as a kind of intellectual hygiene to jolt people out of their assumptions about the natural world. In Aristotelian natural philosophy, monsters and other anomalies were seen as outliers, to be acknowledged but not explained. Bacon turned the tables and used monsters as a weapon against the ruling orthodoxy in natural philosophy and natural history.

Were monsters seen as frightening?

That was certainly one view. Birth deformations, like two-headed cats and conjoined twins, were terrifying but also electrifying. They seemed to be a telegram from God announcing the end of time, the end of the world. But in another context, they were seen as wonders—not as terrifying, but astonishing, a sign of the fecundity, the creativity, and the variety of nature. So the emotional response could flip over from one moment to the next, from horror to wonder and back again. In one early 17th-century sermon in an English parish about the birth of conjoined twins, the minister harangued his parishioners not to treat this monstrous birth as a wonder to be gawked at and admired, but as a horrifying portent that they should repent immediately.

How did this struggle to explain unlikely occurrences relate to the birth of modern science?

These anomalies were seen as challenges. By the 17th century, it was pretty clear that Aristotelian natural philosophy was doomed. The question was what would replace it, and there were lots of fiercely competing theories. Monsters and other marvels offered extreme cases. Could your revision of natural philosophy explain such things? This made monsters and wonders more prominent in the late 16th and early 17th centuries than they've ever been before or since in the history of science. For the most part, science is interested in the regularities of nature—and that makes sense. Why would you devote time, thought, and ingenuity to explaining what only happens once in a blue moon? But in this period, anomalies very briefly took center stage when it came to scientific explanations.

What about the founders of modern science—Galileo, Descartes, Newton, Leibniz? What was their interest in nature's oddities?

Descartes thought that if you're putting forward a new theory of everything, you should be able to explain these outlier cases. He even thought you could explain what was considered an old medieval marvel, in which the corpse of a murder victim would bleed again in the presence of the murderer or the murder weapon. Leibniz sent a report of a dog that could talk to the journal of the Paris Academy of Royal Sciences. It could bark out six words in French, including "chocolat." Everyone was trafficking in marvels in the 17th century.

You've described this transitional period between premodern and modern science as "the great age of wonder." What kinds of wonders were scientists finding?

Let's take astronomy. In 1609, Galileo turned his telescope to the heavens. He discovered the surface of the moon was pockmarked by craters. He discovered four moons of Jupiter, which he described as "marvels." He discovered the phases of Venus. He published these findings in 1610, and it caused a sensation. This book

They seemed to be a telegram from God announcing the end of time, the end of the world.

sold like hot cakes. Rumors were even more salacious in European gossip circuits. There were spectacular novelties coming from the New World and also from China and the Far East, streaming into the markets of London and Amsterdam.

So this was partly the result of new global commerce.

A lot of these marvels could have been seen as commodities. When we think of the ancestors of our museums—the "cabinets of curiosity," *wunderkammern*—they are chock-full of marvels and monsters of all kinds. We wouldn't see some of these things as marvels, such as paper money from China. But from the standpoint of late-16th-century Europeans, the concept of accepting paper money instead of gold or silver was almost as much a marvel as an armadillo.

***Wunderkammern* is usually translated as "cabinets of curiosity," but isn't "cabinets of wonder" a better translation?**

"Chambers of wonders" would be the literal translation.

Do "wonder" and "curiosity" mean the same thing?

No. What's distinctive about this period is that wonder and curiosity are yoked together. Aristotle had said wonder is "the beginning of philosophy," but the aim of his natural philosophy was to make wonder disappear as soon as possible. It was a sign that you were ignorant at best, or at worst you were timorous or fearful. Since ancient times, curiosity was associated with vice rather than virtue, with people who meddled in other people's business. You were meddling in secrets that shouldn't concern you—the secrets of Nature, of God, of the Prince.

Of course, the classic cautionary tale about curiosity is Adam and Eve, who tasted fruit from the forbidden Tree of Knowledge. It was the original sin.

Absolutely. And then what happens in the 16th and 17th centuries is fascinating. Curiosity goes from being a real vice to a virtue. It becomes a form of audacity. "Dare to know" becomes a motto that natural philosophers are proud to make their own, and wonder goes

from being a sign of ignorance to a desire for knowledge. The clearest expression of this is in Descartes' 1649 treatise, *Passions of the Soul*. First wonder and then curiosity are engaged, and the two work together. Wonder is like the spark that ignites the fuse of curiosity. Curiosity then marshals the intellect and all the senses in the quest to find the cause of wonder.

Tell me about the *wunderkammern*, these cabinets of wonder. What did people collect?

What didn't they collect? In order to qualify for a *wunderkammer*, the objects had to be unusual. So they could simply be exotic—such as paper money from China or pointed toe slippers from Turkey. Or wondrous because they're mistakes of nature, like two-headed snakes. Or because they are virtuoso works of art—a thousand faces carved upon one cherry stone.

The ways they were displayed were intended to accentuate the hodge-podgery of it all, to accentuate diversity, miscellany, and also plenitude. Maybe you've seen pictures of these floor-to-ceiling displays, which have everything from Ceylon shields to a stuffed Laplander to a crocodile hanging from the ceiling.

The aim of a *wunderkammer*, especially a prince's collection, was to overwhelm you. They were often shown to ambassadors to impress them with the power of the prince. Today's museums have a lot in common with these early *wunderkammern*. They're meant to astonish us, to jolt us out of our everyday thoughts: "Fancy seeing that!" And they're meant to provoke our curiosity, to make us inquisitive about some new class of objects. Probably only in museums is that alliance of wonder and curiosity still preserved in its full intensity.

Yet from our modern perspective, this mix of man-made objects and oddities of nature is strange. The distinction between nature and art seems so obvious today.

It would also have been obvious in the 14th and 15th centuries. So it's really interesting what happens in the early modern period. Monsters and other marvels were used as catalysts to accelerate new theories of knowledge. Again, it's Bacon's formulation. These marvels are experiments that Nature is performing on herself. And if we want to create a new way of tempering steel or dying fabric, we should look very closely at these experiments that Nature is performing on the margins of its regular order. Then we should imitate Nature.

Was Nature seen as God's great artistic creation?

The more devout would have formulated it that way. And for 16th- and 17th-century philosophers, Nature is allowed to joke. What we would now call a fossil—the impress of a fern in rock—might have been interpreted in the early 17th century as a joke of Nature. "Oh, what the heck! I'm tired of creating leaf-like forms in trees and plants. Let's try it in stone." But God is not allowed to joke. So Nature had the freedom to experiment, which was exactly what the natural philosophers needed Nature for. To suggest that God was experimenting would have bordered on the blasphemous.

Today we categorize and collect objects of nature and art in entirely different ways. Paintings and sculptures go in art museums, while seashells and stuffed animals go in natural history museums. Apparently those distinctions were not made in cabinets of wonder.

Sometimes I suspect the reporters of The National Enquirer *go back to the early scientific journals for their ideas.*

It was all one great, glorious miscellany. I think you can date the end of the age of wonder precisely by that division of labor between art museums and natural history museums in the mid-to-late 18th century.

Why did wonder go out of fashion?

From the scientific standpoint, if you look at the annals of the first scientific societies—the Royal Society of London and the Paris Academy of Royal Sciences—the first six to 30 years are filled with reports of monsters and marvels. They read like *Ripley's Believe It or Not* or *The National Enquirer*. Bacon thought we have to look at these anomalies if we're really going to discover the deep secrets of nature.

But by the 1730s and '40s, scientists had wearied of anomalies and began to feel it was time to return to the main business of science, which was to explain regularities. There was also ecclesiastical uneasiness with these marvels because they were objects of religious fervor. This was the time of the Reformation and Counter-Reformation, and new sects were sprouting up like mushrooms. The leaders of these new sects would often point to marvels as signs that God was on their side.

You've used the term "natural philosophy" to describe the work of these early thinkers. Is this another term for "science?"

I'm not just being a finicky historian. I don't want to equate natural philosophy with what we know today as modern science. The institution of science happens much later in the 19th century, so it was rare to make a living practicing science. Natural philosophers also asked bigger questions than scientists would. Newton thought it was perfectly in order to speculate on the relationship between gravitation and the nature of God. This would be completely unacceptable to a modern scientist. So natural philosophy is the ancestor of modern science, but they are not identical.

There's a kind of Bermuda Triangle of terror, horror, and wonder, which have deep subterranean connections.

LORRAINE DASTON

LORRAINE DASTON, PHOTOGRAPH COURTESY OF SKÚLI SIGURDSSON

We've been talking about wonders and marvels. There's also the different, emotional experience of "wonder" itself, which is closer to awe. Does wonder have its own history?

It does. We in the modern period associate wonder with a childlike stance, a freshness of vision. But in the medieval and early modern period, there's nothing childish about it. Wonder could very easily tip over into horror or terror. There's a kind of Bermuda Triangle of terror, horror, and wonder, which have deep subterranean connections with each other. They all involve the perception that something extraordinary has happened. And they wobble. They can easily transmute from one into the other.

Wonder is tinged with awe—which can put it into the realm of the supernatural, perhaps even the divine—and it's also tinged with fear. It's an uncomfortable emotion. You don't have wonder. Wonder has you. It grabs you by the lapels and shakes you. Wonder is also associated with fear, and it's very embarrassing for a learned person to be seen as fearful. Wonder is for the ignorant, the unlettered. You, the university professor of natural philosophy, wish to show that you are not terrified of an eclipse because you can explain it, even predict it.

So this is really a question of what can be explained, which is the essence of science.

And it's really interesting to see what happens during the mid-18th century, when natural philosophers begin to abandon the marvels and return to the regularities. They transform wonder from the astonishing and the inexplicable to that which they explain. There's a concerted attempt to transfer wonder from monstrous births to very ordinary and even disgusting objects, like insects. There's a whole genre of natural history involving the marvels of insects, which is an attempt to domesticate the emotion of wonder for things we can explain.

It's extremely difficult to get into the mindset of people who lived 300 years ago, to overcome our tendency to impose our own biases on the past. It would be easy to write them off as ignorant or uneducated. Is that

part of your work, to say they were just different, not lesser, than we are today?

That's very well put. The whole premise of doing the history of pre-modern science is that these were extraordinarily intelligent and often courageous people who, without any of the institutional props of universities or laboratories, were trying their damnedest to figure out how the world works, at the expense of their fortunes, often their health, and sometimes their lives.

The Scientific Revolution was remarkable. But some people think we've lost something in our current age of rationality and science. They talk about how the world has become "disenchanted," that we've lost the capacity to be swept away by wonder. Do you see that as a problem?

I don't. It's very difficult to square this morose and elegiac discourse about the disenchantment of the world, which was very common in the early 20th century, with any working scientist who is afire with enthusiasm and delight and wonder about what he or she is working on. I mean, why do these people voluntarily work 80 hours a week?

In the epilogue of *Wonders and the Order of Nature*, you quote William James, the great philosopher and psychologist, who lived a century ago. He believed science would be renewed by what he called "the dust-cloud of exceptional observations." He was also fascinated by spiritualism. He and his small cohort of scientists actually investigated seances, which most scientists scoffed at. Did James have a point?

He absolutely had a point. He wrote about "radical empiricism." That's what the interest in wonders was. It was the desire to exclude absolutely nothing from the purview of inquiry—not to narrow one's gaze for expedience or orthodoxy, but to accept the world as it presents itself to us.

I think all science involves a receptivity to the anomalous, perhaps not in the splashy sense of a marvel, but simply an eye attuned to, "Oh, that's odd, that hasn't happened before." There's the famous story of penicillin's discovery. No doubt others before Alexander Fleming saw mold growing in petri dishes, but he was receptive to the oddity of it, the strangeness of it, and pursued it. And that story is told over and over again in the annals of scientific anecdote. It's a kind of observational openness to small deviations from the norm and the willingness to hunt them to ground.

The scientific sensibility is now attuned to objects that most of us would not consider intrinsically wondrous in the way a two-headed snake would be. It's as if scientists are connoisseurs of marvels, just as real gourmets with refined silver palettes are looking for esoteric combinations of flavors. Someone without a refined palette might be swept away by a fairly ordinary meal. Scientists are looking for much more unusual and esoteric combinations.

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Why We Keep Playing the Lottery

Blind to the mathematical odds, we fall to the marketing gods

BY ADAM PIORE

ILLUSTRATIONS BY ELLEN WEINSTEIN

TO GRASP HOW UNLIKELY it was for Gloria C. MacKenzie, an 84-year-old Florida widow, to have won the $590 million Powerball lottery in May, Robert Williams, a professor of health sciences at the University of Lethbridge in Alberta, offers this scenario: Head down to your local convenience store, slap $2 on the counter, and fill out six numbers on a Powerball ticket. It will take you about 10 seconds. To get your chance of winning down to a coin toss, or 50 percent, you will need to spend 12 hours a day, every day, filling out tickets for the next 55 years. It's going be expensive. You will have to plunk down your $2, 86 million times.

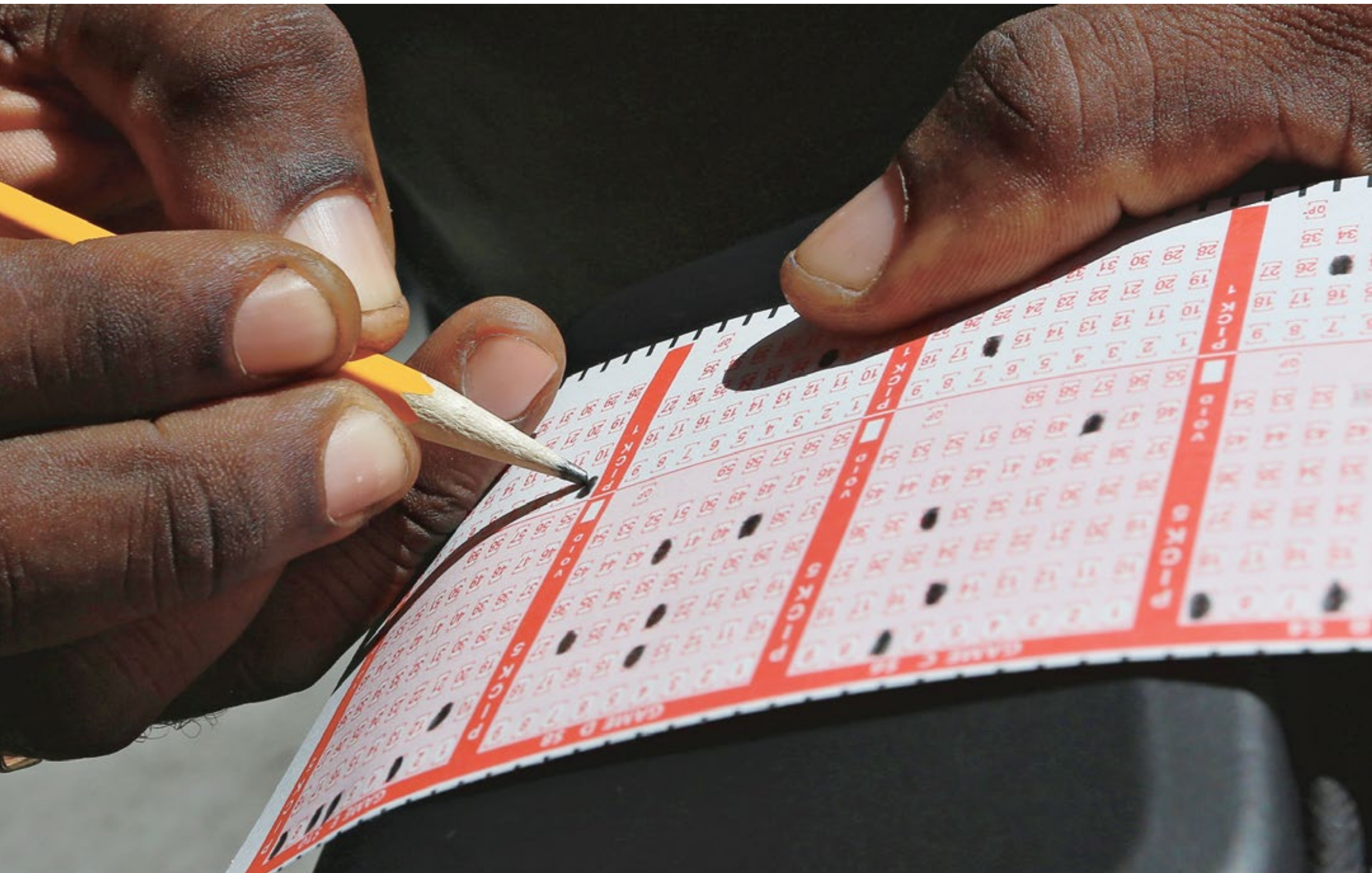
Williams, who studies lotteries, could have simply said the odds of winning the $590 million jackpot were 1 in 175 million. But that wouldn't register. "People just aren't able to grasp 1 in 175 million," Williams says. "It's just beyond our experience—we have nothing in our evolutionary history that prepares us or primes us, no intellectual architecture, to try and grasp the remoteness of those odds." And so we continue to play. And play. People in 43 states bought a total of 232 million Powerball tickets for the lottery won by MacKenzie. In fact, the lottery in the United States is so exceedingly popular that it was one of the few consumer products where spending held steady and, in some states, increased, during the recent recession. That's still the case. About 57 percent of Americans reported buying tickets in the last 12 months, according to a recent Gallup study. And for the 2012 fiscal year, U.S. lottery sales totaled about $78 billion, according to the North American Association of State and Provincial Lotteries.

It may seem easy to understand why we keep playing. As one trademarked lottery slogan goes, "Hey, you never know." Somebody has to win. But to really understand why hundreds of millions of people play a game they will never win, a game with serious social consequences, you have to suspend logic and consider it through an alternate set of rules—rules written by neuroscientists, social psychologists, and economists. When the odds are so small that they are difficult to conceptualize, the risk we perceive has less to do with outcomes than with how much fear or hope we are feeling when we make a decision, how we "frame" and organize sets of logical facts, and even how we perceive ourselves in relation to others. Once you know the alternate set of rules, plumb the literature, and speak to the experts, the popularity of the lottery suddenly makes a lot more sense. It's a game where reason and logic are rendered obsolete, and hope and dreams are on sale. And nobody knows how to sell hope and dreams better than Rebecca Paul Hargrove.

ON MOST DAYS IN a nondescript office park on the outskirts of Nashville, Tenn., you will find Hargrove reclining in a purple executive chair behind a massive desk. She occupies a corner office in the Tennessee Education State Lottery Corporation, where she serves as president.

Hargrove is a lottery legend. In the 1980s and '90s she built the state lotteries in Georgia and Florida from scratch, constructing multibillion-dollar empires that soon surpassed many lotteries that had been around far longer. After two years of Hargrove's leadership, Florida was outselling every other lottery in the nation, including California, which had a population twice

PHOTO BELOW BY MARIO TAMA/GETTY IMAGES—PHOTO ABOVE BY ZOE STRAUSS/MAGNUM PHOTOS



It's a game where reason and logic are rendered obsolete, and hope and dreams are on sale.

Florida's size. When Hargrove left Georgia for Tennessee in 2003, Georgia Lt. Gov. Mark Taylor commented, "Now I know how the Boston Red Sox fans felt. Babe Ruth has been traded to the Yankees." Hargrove, he said, was "the premier lottery executive in the country."

On a sweltering morning in June, I was ushered into Hargrove's second floor corner office. She greeted me warmly, dressed in a pink T-shirt, khaki pants, and a button-down sweater. With a mass of snowy white hair swept back in a loose bun, and a pair of glasses perched precariously on the bridge of her nose, Hargrove came across as a folksy Fairy Godmother, with a gift for schmooze. Within minutes of my arrival, she was spinning out anecdotes about her hairdresser's predilection for cat-themed instant game tickets and the little old lady who lives down the block from her mother and won $56 million.

Hargrove has an intuitive understanding of what drives her customers to play the game. She has a preternatural sense of where their psychological buttons are located and how to push them. She responded in a flash to my comment about the logical futility of playing the lottery. "If you made a logical investment choice, you'd play a different game," she said, leaning forward for emphasis. "It's not an investment. It's entertainment. For a very small amount of money you might change your life. For $2 you can spend the day dreaming about what you would do with half a billion dollars—half a billion dollars!"

In 1985, when Illinois Governor James Thompson tapped Hargrove to head the state lottery, she didn't know much about the business. But the former beauty queen (Miss Indiana 1972, Miss America finalist 1973) did know a thing or two about selling a product. After winning a TV job doing the weekend weather at an ABC affiliate in her hometown of Indianapolis, she moved to Springfield, Ill., to work for a NBC affiliate. In Springfield, she recruited her own TV advertisers and produced her own commercials, demonstrating a natural talent for marketing. She got involved in politics and rose to Illinois Republican State Party Chairwoman, before taking over the Illinois lottery.

In her new job, Hargrove did what any savvy marketer would do: She sat down and thought about her own motivations. "I played the lotto when I was caught up in the frenzy of a $40 million jackpot," she said. "And I thought, 'What made me play?' What made me play was the thought of what I would do with $40 million. You pay $1 and then for three days you can think about that question. Would I share with my brother-in-law? No! I don't like that brother-in-law. But I would share with my neighbor's nephew."

With that simple insight, Hargrove struck marketing gold. More than 200 ads went up on billboards across the state. "How to Get from Washington Boulevard to Easy Street," read one in a poor Chicago neighborhood, displaying a picture of a tantalizing pile of lotto money. Hargrove also pushed for larger, attention grabbing jackpots. In 1987, she played a key role in creating a multistate lottery, consisting of nine states and the District of Columbia, so that jackpots could balloon to as much as $80 million. The excitement generated by the eye-popping jackpots, she figured, would generate more excitement than any one state could create on its own. "The more the jackpot is, the more tickets you sell," she said. "It feeds the dreaming."

From her first days in the lottery business, Hargrove learned to make the lottery fantasy tangible by making sure that winning, on a smaller scale, is something people experience. "If you play a lot and you play for three years and you never win, you're not going to keep playing," Hargrove said.

In Illinois, Hargrove experimented with smaller prizes, which had better odds of winning than the big state Lottos. When she introduced a second weekly Lotto drawing, she saw an immediate 5 percent spike in sales. To prevent player burnout, Hargrove pioneered games with different prices, designs, and themes. She might trot a game where you scratch off cute cats for cat lovers, and a game with footballs for Bears fans. She might sell four leaf clovers on St. Patrick's Day, and reindeer-themed tickets around Christmas. The odds of winning may remain remote, but keeping it "fresh" and "exciting" added a sense of possibility and made it more fun, she said. Hargrove knew that game cards were impulse buys, so she emphasized point-of-purchase advertising. She pushed to make the cards as ubiquitous as "bubble gum."

Sitting in her Tennessee office, her energy never flagging, Hargrove stressed that the lottery raised millions to fund educational programs for the state's

children, and that was something that should always be apparent. The direct link to education "affects everything—it affects how the legislators feel, it affects how the playing public feels about it, it affects how the press feels about you," she said. "All those things add up to a positive experience buying a lottery ticket."

WHILE HARGROVE'S FEEL-GOOD MARKETING goes a long way toward explaining why we keep playing the lottery, scientists are increasingly making it clear how lottery marketing taps into our brains and impacts our communities.

Selling the lottery dream is possible because the probabilities of winning are so infinitesimal they become irrelevant. Our brains didn't evolve to calculate low odds. In our evolutionary past, the ability to distinguish between a region with a 1 percent or 0.1 percent chance of being attacked by a predator wouldn't have offered much of an advantage. An intuitive and coarse method of categorization, such as "doesn't happen," "happen sometimes," "happens most of time," "always happens," would have sufficed, explains Jane L. Risen, an associate professor of Behavioral Science at the University of Chicago, Booth School of Business, who studies decision-making. Despite our advances in reason and mathematics, she says, we still often rely on crude calculations to make decisions, especially quick decisions like buying a lottery ticket.

In the conceptual vacuum created by incomprehensible odds, people are likely to experience magical thinking or superstition, play a hunch, or simply throw reason out the window all together, says George Loewenstein, a professor of economics and psychology at Carnegie Mellon. "Most of the weird stuff that you see with decision-making and risk happens with small probabilities," he says.

One reason may be that uncertainty activates a network of brain areas that push us reflexively to find a resolution. Uncertainty for the brain is a negative state, and so it screams, "'I don't know what to do, I don't know how to act, my organism is at risk,'" says Giorgio Coricelli, an associate professor of economics and psychology at the University of Southern California. "To make the choice, your brain automatically looks for suggestions, searches for more information, and if there is little information, we can make strange associations, assume something is realistic, even if it is superstitious."

There is plenty of historical research to correlate the rise of religion and superstition with uncertainty, Coricelli says. In the same way, he adds, when there is little we can do to raise a probability, we are just as likely to play the lucky number 7 or insist on buying our lottery ticket at a certain time of day to raise our chance of winning.

Our proclivity for fantasy makes us an easy target for advertising. Lottery commercials depict winners in stretch limousines, counting stacks of money, dressed in evening gowns and tuxedos, sipping champagne.

The commercials hit home because fantasizing about winning the lottery activates the same parts of our brains that would be activated if we actually won, notes Daniel Levine, professor of psychology at the University of Texas at Arlington, and an expert on decision theory and neural networks. Picturing ourselves in a limo activates visual areas of the brain, while imagining the clink of champagne glasses lights up the auditory cortex. These areas have links to the brain regions involved in emotion, decision-making, and motivation. "The motivational areas of the brain can be heavily influenced by vivid daydreaming," Levine says. "Just like seeing something can activate the emotional system, so can envisioning it."

But even fantasy will drop its hold on us if we always lose—a point Hargrove grasped from the start. Research has shown that positive reinforcement is a key in virtually all of the successful lotteries, notes the University of Lethbridge's Williams. Lotteries that allow players to choose combinations of four or five numbers from a total of 60 numbers are popular, he says, because many players experience "the near miss," which creates the illusion that they came close to winning the multi-million dollar jackpot. Most players don't realize, however, that "near-miss" is an illusion. The odds of winning get worse with each successive match.

ANOTHER IMPORTANT FACTOR COMES into play as we step up to the cash register at the convenience store: self-image. Lottery sales, it turns out, are heavily influenced by the way we are thinking about the purchase, and the way we perceive ourselves in relation to others when we do.

Carnegie Mellon's Loewenstein and colleagues demonstrated it's possible to change how many lottery tickets people will buy by making them think—or not think—about their purchase in a larger context. The researchers gave one group of study participants $1 at a time, five times, and each time asked them if they wanted to buy a lottery ticket. They gave a second group $5 and asked how many tickets they wanted, while a third group received $5 and was told they had only two choices: They could spend it all on tickets or not buy any tickets at all. The people in the first group purchased twice as many tickets as those asked explicitly what percentage of the $5 they wanted to spend on tickets. Members of the all or nothing group opted for no tickets 87 percent of the time.

One of the things the experiment shows is that lottery players are often "thinking myopically," says Romel Mostafa, who co-authored the 2008 study with Loewenstein, and is now an assistant professor of business, economics, and public policy at Ivey Business School, Western University. "We think about these purchases in one or two at a time. But when the decisions aggregate over time, it adds up. And if I were to bracket the spending over a longer period of time, I would not have bought it in the first place."

This same "framing" phenomenon also helps explain our misperception of the risk. Most people "frame" the lottery as "Boy, I could win $100 million," rather than considering what they might lose, says Princeton economist Hank Farber. "To them, a dollar seems inconsequential," he says.

It's not just the way we frame the odds in the lottery that can affect how likely we are to play the game. It turns out that the way we frame our own economic status can also play a role in our decision to play the lottery.

Mostafa, Loewenstein, and colleagues designed a study to examine the influence that "feeling poor" has on the decision to play the lottery. They approached people at the Pittsburgh Greyhound Bus Depot (who had an average income of $29,228) and asked them to fill out a questionnaire about "community issues." Much of the survey was just window dressing. The only thing researchers cared about were two different versions of multiple choice answers offered for a single question, "How much money do you make." Half received questionnaires with the categories: "less than $10,000, less than $20,000, less than $30,000." The other half

Selling the lottery dream is possible because, paradoxically, the probabilities of winning are so infinitesimal they become irrelevant.

were presented with choices designed to make them feel poor. The categories included "less than $100,000," "less than $200,000," and "less than $300,000."

After completing the questionnaires, the participants were paid $5 and asked if they wanted to use any of the money to buy lottery tickets. Those who had been made to feel poor bought twice as many lottery tickets as those in the control group, the authors wrote in a 2008 study published in the *Journal of Behavioral Decision Making*.

"The lottery is a way to raise the ceiling on what can happen to you," says Loewenstein. "So if you are reminded of your poverty, it makes the idea of lifting the poverty a more salient motive. Lottery tickets become that much more attractive at that moment."

For many poor people, he adds, there is "no scenario they can come up with in which they are suddenly going to get very rich." To them, the lottery may be a low probability event—but so is getting a job that pays six figures.

That point is driven home by a 2006 Consumer Federation of America study, which surveyed 1,000 Americans about their personal views on wealth. The survey found that 21 percent of Americans—38 percent of whom had incomes below $25,000—thought that winning the lottery represented the "most practical" way for them to accumulate several hundred thousand dollars.

"A lot of people say that the lottery is a regressive tax, which is true," Loewenstein says, referring to taxes that aren't pegged to income, and take a larger proportion of income from those who can least afford it. (A person who makes $15,000 a year and buys $1,500 worth of lottery tickets has spent 10 percent of his income, while a person who makes $150,000 and buys $1,500 has spent only 1 percent.) "It is true that poor people spend a substantially higher fraction of their income on lottery tickets" than the affluent, he notes. "But I don't think it is necessarily irrational. Buying lottery tickets is a fairly inexpensive way of raising the ceiling on what can happen to you economically." In other words, when your economic prospects are dim, buying hope makes sense.

HOW WE PERCEIVE OURSELVES in relation to others also shapes our decision to play the lottery—a lever the industry consistently pulls. A salient example is the "Postcode Lottery" in the Netherlands. Weekly it awards a "Street Prize" to one postal code, the Dutch equivalent of a zip code, chosen at random. When a postal code (usually about 25 houses on a street) is drawn, everybody who has played the lottery in that code wins about $12,500 or more. Those living there who neglected to buy a ticket prior to the drawing win nothing—except the chance to watch their neighbors celebrate. In secondary drawings, many of those who purchased tickets in the winning postcode win BMWs, and are eligible to win as much as $14 million—$7 million for one lucky winner picked from within the winning postcode, and $7 million for their immediate neighbors who bought tickets.

In a 2003 study, researchers in the departments of economic and social psychology and marketing at Tilburg University in the Netherlands, noted fear of regret played a significantly larger role in the Postcode Lottery than in a regular lottery. It was not the chance of winning that drove the players to buy tickets, the researchers found, it was the idea that they might be forced to sit on the sidelines contemplating missed opportunity. The promoters of the Postcode Lottery seemed well aware of that. One mailer read: "Sour, that is how it feels when you miss an amount of at least 2 million by just an inch. Because seeing a multimillion dollar prize fall on your own address, but winning nothing since you did not buy a ticket, that is something that you do not want to experience."

"The brain is very sensitive to loss—even low probability losses," explains USC's Coricelli. "So if you frame something as a loss, biologically there is a compulsion to avoid it. We have an aversion to it."

In fact, says Levine of UT Arlington, we are hardwired to evaluate gains or losses based not on their own terms, but in comparison with other people. "If you don't see anybody in a limo, you can be perfectly happy with your Honda Civic," Levine says. "But if you do, you might feel less happy with what you have. It is a comparison. You can manipulate people into potentially feeling regret when they see other people getting more than they have."

In the end, fear and regret are the flipsides of hope and dreams—all are powerful emotions that when tapped can cause us to relinquish rationality, to act on instinct, even to make decisions that might not be in our best interest. As I left Hargrove's office and drove along the Tennessee Interstate toward the airport, I scanned the highway for the giant Powerball billboards that she had touted as the best marketing tool in her arsenal. She didn't need many words to get her message across, as the billboard that week trumpeted, in 10-foot-high digital numbers, a $100 million jackpot. I couldn't help but think, as I drove along, "What would I do with that much money?"

ADAM PIORE is a freelance writer based in New York.

The Man Who Invented Modern Probability

Chance encounters in the life of Andrei Kolmogorov

BY SLAVA GEROVITCH

ILLUSTRATION BY LINCOLN AGNEW

IF TWO STATISTICIANS WERE to lose each other in an infinite forest, the first thing they would do is get drunk. That way, they would walk more or less randomly, which would give them the best chance of finding each other. However, the statisticians should stay sober if they want to pick mushrooms. Stumbling around drunk and without purpose would reduce the area of exploration, and make it more likely that the seekers would return to the same spot, where the mushrooms are already gone.

Such considerations belong to the statistical theory of "random walk" or "drunkard's walk," in which the future depends only on the present and not the past. Today, random walk is used to model share prices, molecular diffusion, neural activity, and population dynamics, among other processes. It is also thought to describe how "genetic drift" can result in a particular gene—say, for blue eye color—becoming prevalent in a population. Ironically, this theory, which ignores the past, has a rather rich history of its own. It is one of the many intellectual innovations dreamed up by Andrei Kolmogorov, a mathematician of startling breadth and ability who revolutionized the role of the unlikely in mathematics, while carefully negotiating the shifting probabilities of political and academic life in Soviet Russia.

As a young man, Kolmogorov was nourished by the intellectual ferment of post-revolutionary Moscow, where literary experimentation, the artistic avant-garde, and radical new scientific ideas were in the air. In the early 1920s, as a 17-year-old history student, he presented a paper to a group of his peers at Moscow University, offering an unconventional statistical analysis of the lives of medieval Russians. It found, for example, that the tax levied on villages was usually a whole number, while taxes on individual households were often expressed as fractions. The paper concluded, controversially for the time, that taxes were imposed on whole villages and then split among the households, rather than imposed on households and accumulated by the village. "You have found only one proof," was his professor's acid observation. "That is not enough for a historian. You need at least five proofs." At that moment, Kolmogorov decided to change his concentration to mathematics, where one proof would suffice.

It is oddly appropriate that a chance event drove Kolmogorov into the arms of probability theory, which at the time was a maligned sub-discipline of mathematics. Pre-modern societies often viewed chance as an expression of the gods' will; in ancient Egypt and classical Greece, throwing dice was seen as a reliable method of divination and fortune telling. By the early 19th century, European mathematicians had developed techniques for calculating odds, and distilled probability to the ratio of the number of favorable cases to the number of all equally probable cases. But this approach suffered from circularity—probability was defined in terms of equally probable cases—and only worked for systems with a finite number of possible outcomes. It could not handle countable infinity (such as a game of dice with an infinite number of faces) or a continuum (such as a game with a spherical die, where each point on the sphere represents a possible outcome). Attempts to grapple with such situations produced contradictory results, and earned probability a bad reputation.

Pre-modern societies often viewed chance as an expression of the gods' will; in ancient Egypt and classical Greece, throwing dice was seen as a reliable method of divination and fortune telling.

Reputation and renown were qualities that Kolmogorov prized. After switching his major, Kolmogorov was initially drawn into the devoted mathematical circle surrounding Nikolai Luzin, a charismatic teacher at Moscow University. Luzin's disciples nicknamed the group "Luzitania," a pun on their professor's name and the famous British ship that had sunk in World War I. They were united by a "joint beating of hearts," as Kolmogorov described it, gathering after class to exalt or eviscerate new mathematical innovations. They mocked partial differential equations as "partial irreverential equations" and finite differences as "fine night differences." The theory of probability, lacking solid theoretical foundations and burdened with paradoxes, was jokingly called the "theory of misfortune."

It was through Luzitania that Kolmogorov's evaluation of probability took on a more personal turn. By the 1930s, the onset of Stalinist terror meant that anyone could expect a nighttime knock on the door by the secret police, and blind chance seemed to rule people's lives. Paralyzed by fear, many Russians felt compelled to participate in denunciations, hoping to increase their chance of survival. Bolshevik activists among the mathematicians, including Luzin's former students, accused Luzin of political disloyalty and castigated him for publishing in foreign countries. Kolmogorov, having published abroad himself, may have realized his own vulnerability. He had already displayed an apparent readiness to make political compromises for the sake of his career, accepting a position as a research institute director when his predecessor was imprisoned by the Bolshevik regime for supporting religious freedom. Now Kolmogorov joined the critics and turned against Luzin. Luzin was subject to a show trial by the Academy of Sciences and lost all official positions, but surprisingly escaped being arrested and shot by the Russian authorities. Luzitania was gone, sunk by its own crew.

The moral dimension of Kolmogorov's decision aside, he had played the odds successfully and gained the freedom to continue his work. In the face of his own political conformity, Kolmogorov presented a radical and, ultimately, foundational revision of probability theory. He relied on measure theory, a fashionable import to Russia from France. Measure theory represented a generalization of the ideas of "length," "area," or "volume," allowing the measure of various weird mathematical objects to be taken when conventional means did not suffice. For example, it could help calculate the area of a square, with an infinite number of holes in it, cut it into an infinite number of pieces, and scattered over an infinite plane. In measure theory, it is still possible to speak of the "area" (measure) of this scattered object.

Kolmogorov drew analogies between probability and measure, resulting in five axioms, now usually formulated in six statements, that made probability a respectable part of mathematical analysis. The most basic notion of Kolmogorov's theory was the

Mathematics had led him to believe that the world was both driven by chance and fundamentally ordered according to the laws of probability.

“elementary event,” the outcome of a single experiment, like tossing a coin. All elementary events formed a “sample space,” the set of all possible outcomes. For lightning strikes in Massachusetts, for example, the sample space would consist of all the points in the state where lightning could hit. A random event was defined as a “measurable set” in a sample space, and the probability of a random event as the “measure” of this set. For example, the probability that lightning would hit Boston would depend only on the area (“measure”) of this city. Two events occurring simultaneously could be represented by the intersection of their measures; conditional probabilities by dividing measures; and the probability that one of two incompatible events would occur by adding measures (that is, the probability that either Boston or Cambridge would be hit by lightning equals the sum of their areas).

The Paradox of the Great Circle was a major mathematical conundrum that Kolmogorov’s conception of probability finally put to rest. Assume aliens landed randomly on a perfectly spherical Earth and the probability of their landing was equally distributed. Does this mean that they would be equally likely to land anywhere along any circle that divides the sphere into two equal hemispheres, known as a “great circle?” It turns out that the landing probability is equally distributed along the equator, but is unevenly distributed along the meridians, with the probability increasing toward the equator and decreasing at the poles. In other words, the aliens would tend to land in hotter climates. This strange finding might be explained by the circles of latitude getting bigger

RIA NOVOSTI / SCIENCE SOURCE IMAGES

Opposite: Andrei Kolmogorov, photographed in 1980.

Music and literature were deeply important to Kolmogorov, who believed he could analyze them probabilistically to gain insight into the inner workings of the human mind.

as they get closer to the equator—yet this result seems absurd, since we can rotate the sphere and turn its equator into a meridian. Kolmogorov showed that the great circle has a measure zero, since it is a line segment and its area is zero. This explains the apparent contradiction in conditional landing probabilities by showing that these probabilities could not be rigorously calculated.

Having crossed from the very real world of Stalinist purges into the ephemeral zone of zero-measure conditional probabilities, Kolmogorov was soon plunged back into reality. During World War II, the Russian government asked Kolmogorov to develop methods for increasing the effectiveness of artillery fire. He showed that, instead of trying to maximize the probability of each shot hitting its target, in certain cases it would be better to fire a fusillade with small deviations from perfect aim, a tactic known as "artificial dispersion." The Moscow University Department of Probability Theory, of which he had become the head, also calculated ballistic tables for low-altitude, low-speed bombing. In 1944 and 1945, the government awarded Kolmogorov two Orders of Lenin for his wartime contributions, and after the war, he served as a mathematics consultant for the thermonuclear weapons program.

But Kolmogorov's interests inclined him in more philosophical directions, too. Mathematics had led him to believe that the world was both driven by chance and fundamentally ordered according to the laws of probability. He often reflected on the role of the unlikely in human affairs. Kolmogorov's chance meeting with fellow mathematician Pavel Alexandrov on a canoeing trip in 1929 began an intimate, lifelong friendship. In one of the long, frank letters they exchanged, Alexandrov chastised Kolmogorov for the latter's interest in talking to strangers on the train, implying that such encounters were too superficial to offer insight into a person's real character. Kolmogorov objected, taking a radical probabilistic view of social interactions in which people acted as statistical samples of larger groups. "An individual tends to absorb the surrounding spirit and to radiate the acquired lifestyle and worldview to anyone around, not just to a select friend," he wrote back to Alexandrov.

Music and literature were deeply important to Kolmogorov, who believed he could analyze them probabilistically to gain insight into the inner workings of the human mind. He was a cultural elitist who believed in a hierarchy of artistic values. At the pinnacle were the writings of Goethe, Pushkin, and Thomas Mann, alongside the compositions of Bach, Vivaldi, Mozart, and Beethoven—works whose enduring value resembled eternal mathematical truths. Kolmogorov stressed that every true work of art was a unique creation, something unlikely by definition, something outside the realm of simple statistical regularity. "Is it possible to include [Tolstoy's *War and Peace*] in a reasonable way into the set of 'all possible novels' and further to postulate the existence of a certain probability distribution in this set?" he asked, sarcastically, in a 1965 article.

Yet he longed to find the key to understanding the nature of artistic creativity. In 1960, Kolmogorov armed a group of researchers with electromechanical calculators and charged them with the task of calculating the rhythmical structures of Russian poetry. Kolmogorov was particularly interested in the deviation of actual rhythms from classical meters. In traditional poetics, the iambic meter is a rhythm consisting of an unstressed syllable followed by a stressed syllable. But in practice, this rule is rarely obeyed. In Pushkin's *Eugene Onegin,* the most famous classical iambic poem in the Russian language, almost three-fourths of its 5,300 lines violate the definition of the iambic meter, and more than a fifth of all even syllables are unstressed. Kolmogorov believed that the frequency of stress deviation from the classical meters offered an objective "statistical portrait" of a poet. An unlikely pattern of stresses, he thought, indicated artistic inventiveness and expression. Studying Pushkin, Pasternak, and other Russian poets, Kolmogorov argued that they had manipulated meters to give "general coloration" to their poems or passages.

To measure the artistic merit of texts, Kolmogorov also employed a letter-guessing method to evaluate the entropy of natural language. In information theory, entropy is a measure of uncertainty or unpredictability, corresponding to the informational content of a message: the more unpredictable the message, the more information it carries. Kolmogorov turned entropy into a measure of artistic originality. His group conducted a series of experiments, showing volunteers a fragment of Russian prose or poetry and asking them to guess the next letter, then the next, and so on. Kolmogorov privately remarked that, from the viewpoint of information theory, Soviet newspapers were less informative than poetry, since political discourse employed a large number of stock phrases and was highly predictable in its content. The verses of great poets, on the other hand, were much more difficult to predict, despite the strict limitations imposed on them by the poetic form. According to Kolmogorov, this was a mark of their originality. True art was unlikely, a quality probability theory could help to measure.

Kolmogorov scorned the idea of placing *War and Peace* in a probabilistic sample space of all novels—but he could express its unpredictability by calculating its complexity. Kolmogorov conceived complexity as the length of the shortest description of an object, or the length of an algorithm that produces an object. Deterministic objects are simple, in the sense that they can be produced by a short algorithm: say, a periodic sequence of zeroes and ones. Truly random, unpredictable objects are complex: Any algorithm reproducing them would have to be as long as the objects themselves. For example, irrational numbers—those that cannot be written as fractions—almost surely have no pattern in the numbers that appear after the decimal point. Therefore, most irrational numbers are complex objects, because they can be reproduced only by writing out the actual sequence. This understanding of complexity fits with the intuitive notion that there is no method or algorithm that could predict random objects. It is now crucial as a measure of the computational resources necessary to specify an object, and finds multiple applications in modern-day network routing, sorting algorithms, and data compression.

By Kolmogorov's own measure, his life was a complex one. By the time he died, in 1987 at the age of 84, he had not only weathered a revolution, two World Wars, and the Cold War, but his innovations left few mathematical fields untouched, and extended well beyond the confines of academe. Whether his random walk through life was of the inebriated or mushroom-picking variety, its twists and turns were neither particularly predictable nor easily described. His success at capturing and applying the unlikely had rehabilitated probability theory, and had created a terra firma for countless scientific and engineering projects. But his theory also amplified the tension between human intuition about unpredictability and the apparent power of the mathematical apparatus to describe it.

For Kolmogorov, his ideas neither eliminated chance, nor affirmed a fundamental uncertainty about our world; they simply provided a rigorous language to talk about what cannot be known for certain. The notion of "absolute randomness" made no more sense than "absolute determinism," he once remarked, concluding, "We can't have positive knowledge of the existence of the unknowable." Thanks to Kolmogorov, though, we can explain when and why we don't.

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Outsmarting the CERNageddon

Can the Large Hadron Collider spawn black holes at full power? CERN investigates

BY ERIK VANCE

IT'S A SUNNY SUMMER day in Geneva, Switzerland. The birds are singing while lovers canoodle near the Jet d'Eau. Somewhere, someone is listening to techno music a little too loudly.

Nearby, 570 feet belowground, the Large Hadron Collider, or LHC, hums away at full power, whipping up lead atoms to near the speed of light before slamming them into protons to see how they explode. The 17-mile tunnel generates 14 trillion electron volts at a collision point six thousandths of an inch across. It is the largest and most powerful machine ever built by humans and the signature scientific experiment of the 21st century.

Suddenly, the ground begins to rumble. It shakes and then rends apart, as if ruptured by a monster deep within. There isn't even time to scream before the earth gives way—pulled inward at terrifying speed—carrying lovers, fountains, and techno music down into the horrible maw of blackness that was once our planet's core. In seconds, it's over. Earth has evaporated into an empty black nothingness.

This was the doomsday scenario put before physicists in 2008, as the LHC was revving up for its first run. Fed by news reports morbidly fascinated with apocalyptic scenarios, the public was genuinely worried that humans were about to create microscopic black holes, or otherwise bizarre matter, that could destroy the world in mere seconds.

Almost all physicists say this scenario is beyond unlikely. As far as we know, black holes form when a massive star collapses on itself in a huge implosion once it burns up all its fuel—not when subatomic particles are slammed together at high speed. But unlikely as it was, the prospect touched all of us—the whole planet. With such high stakes, the concept of risk takes on a whole new meaning. So, physicists studied the apocalyptic hypothesis through a series of three unlikely events: that tiny black holes could form in the first place; that they could last longer than a millisecond; and that they could stick around and swallow everything nearby.

The first unlikely event—creating an ultrasmall black hole—would be a revelation, says Don Lincoln, a physicist at Fermilab near Chicago. He would actually be delighted if it were a scientific possibility. "Oh, my God, I'd be wiggling like a puppy. Somebody'd be going to Stockholm over that one," he says. "If they form, we can learn something deep and insightful and really central to our understanding of how the universe came into existence."

That "something" would be the existence of extremely small extra dimensions in our universe beyond the usual four (three spatial, plus time). It's a little hard to imagine what a miniature dimension would look like or how it would function, but theorists have used the concept to explain why gravity in our universe is so weak (theoretically, it should be stronger). But when it comes to black holes, gravity is everything. Theoretically, if there are five to seven dimensions hidden within the universe, one might squeeze a tiny black hole into being for a fraction of a second.

That's where the second unlikely event comes into play. Everything we know about black holes says that they give off a type of weak energy called Hawking radiation, named after Stephen Hawking. However, remember that Einstein showed that mass equals energy—so you can't lose one without losing the other. Therefore, if tiny black holes could be born, they would immediately puff out of existence.

But let's pretend for a moment that Einstein and Hawking were either wrong or just didn't understand the physics of infinitesimal multidimensional universes. There's the third unlikely event that needs to happen: The minuscule black hole must consume everything around it. But the nearby atoms would be huge compared to that black hole, so it wouldn't find "food" to consume.

It wasn't the first time that physicists pondered particle-induced apocalypses. In 1979, a group of Berkeley scientists wondered if their newly retrofitted collider in the California hills posed some kind of threat. They decided that the very existence of Earth was proof it did not.

Their reasoning was that Earth—and everything else in the universe—is constantly pelted with cosmic rays, which are essentially charged particles not unlike those used by the LHC. There's not much difference between a particle slamming into the Earth and two particles slamming into each other, scientists thought. After billions of years of cosmic bombardment, no black holes or other strange matter have destroyed our planet; so one or more of the three unlikely events must, in fact, be impossible. For instance, black holes may indeed form from such collisions, but even if they did, they might then blow harmlessly out into space—the same way, say, neutrinos do—without touching a single atom.

This idea prevailed until the late 1990s, when the LHC's predecessor, the Relativistic Heavy Ion Collider (RHIC, pronounced "Rick") was coming online in Suffolk, NY. As scientists contemplated potential dangers, two small cracks formed in that safety theory. The first came from a legendary black hole physicist, William Unruh, who said that if one further twists what we know of black holes, Hawking radiation might not actually exist. Granted, he told *The New York Times*, physics "would really, really have to be weird" for this to work. It would be like waking up tomorrow to find gravity no longer exists, or that land and ocean had switched places. Nonetheless, The European Organization for Nuclear Research (CERN) formed a team to investigate the dangers and put the whole end-of-the-world business to rest.

Michelangelo Mangano, one of the CERN physicists charged with the examination, soon realized that there was a second flaw in the safety model—namely that LHC collider beams were actually different from cosmic rays. The cosmic rays that hit Earth behave similarly to a speeding train that hits a parked car—both go careening off roughly in the direction the train was heading. But LHC would essentially slam two trains into each other in a head-on collision, which would cause them to stop in place after a phenomenally powerful blow. Converting that metaphor to colliding beams, if a black hole were formed it wouldn't careen harmlessly out to space, but might instead sit around and interact with nearby atoms—and ultimately swallow everything around it.

To investigate what happens when high-velocity particles collide head-on like trains, Mangano needed a testing ground—someplace in the galaxy where such particles actually ram into each other and come to a screeching halt. Neutron stars fit the specs, he decided. A neutron star is a type of collapsed massive star whose gravity is so strong that any cosmic ray that hit it would be stopped in its tracks like a train that hit a mountain. If black holes could form, and if they didn't puff out immediately, then they would sit in place and gobble up the neutron star. Thus, Mangano reasoned, the existence of neutron stars was proof that such micro black holes don't exist.

Mangano called string theorist Steven Giddings, who had written one of the first papers suggesting such black holes could not be created, and sought his opinion. He was surprised to learn that Giddings's thinking reflected his own, and he was looking at neutron stars as a testing ground, too. They paired up and began collaborating.

They quickly realized how hard the work would be. They had to understand not only the physics of neutron stars (super-dense objects the size of London, but twice the sun's mass), but also the behavior of different types of cosmic rays, and tiny theoretical black holes. "It was extremely exciting," Mangano says. "It was like being back as a graduate student, where every day you open a book and there is something new. But doing it with the wisdom of a seasoned researcher."

Many of their colleagues thought they were wasting their time chasing phantoms, but the pair persisted for months until they suddenly hit a brick wall. They realized that the gravity of a neutron star was too strong for a cosmic particle to penetrate with any speed. Essentially, as soon as a particle got close to the star, it would slow down too much to hit any other particles with LHC-like energy. All their work was for naught.

"It was more than disappointing, it was super-frustrating. It was just a terrible moment. We went through the calculations several times just to be sure that was the case," Mangano says. "And it was a huge heartbreak because we thought we were done."

So, Giddings and Mangano gathered themselves up and started again. This time, the scientists chose white dwarfs—a type of collapsed star that's the size of Earth with the mass of the sun—as their models. White dwarfs are sufficiently dense to stop a careening tiny black hole, but not strong enough to prevent the collision from happening. The duo dove in and found eight white dwarfs which were of the right mass and which had been around long enough to ascertain that tiny black holes formed by particle collisions weren't consuming them. The existence of white dwarfs—particularly those eight—despite 100 million years of cosmic ray pounding was proof that the LHC was safe.

The public was genuinely worried that humans were about to create microscopic black holes, or otherwise bizarre matter, that could destroy the world in mere seconds.

PHOTO COURTESY OF CERN

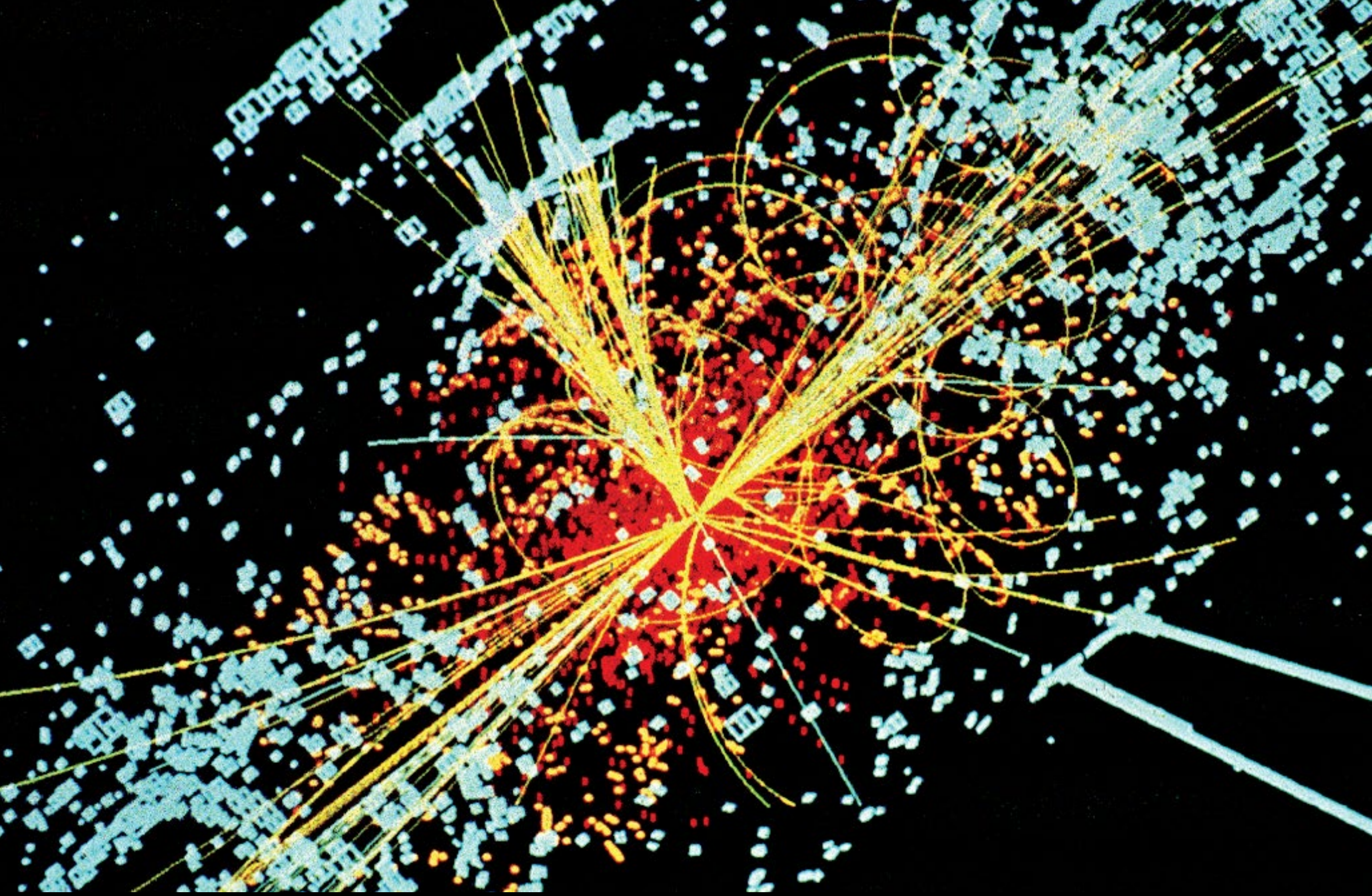

PHOTO COURTESY OF CERN

The nearby atoms would be huge compared to that black hole, so it wouldn't find "food" to consume.

After a year of work, in 2008, Giddings and Mangano published "Astrophysical Implications of Hypothetical Stable TeV-scale Black Holes" in *Physical Review D*. CERN also released two reports summarizing their results, each more confident than the last. The papers were met with a combination of relief and elation—less that the world was safe than that the LHC's funding was, and that the whole mess was over. One astrophysicist, Rainer Plaga, did raise a couple of questions, but beyond that, the paper put the scientific community at ease.

It didn't necessarily convince the rest of the world however. Several vocal opponents without strong science credentials have tried to sue to halt the experiment, but all the cases have been thrown out either on technicalities or lack of jurisdiction. That brought to light a more mundane, though practical, question: What would such a trial look like? It's unclear at the moment since, as a transnational partnership similar to the United Nations, CERN has immunity from most European laws. Also, it would be tricky to find independent voices for such a trial, says Eric Johnson, a lawyer who wrote a detailed review of this legal situation.

"The scientific inquiry was driven by the project schedule of the experiment. I think you can say that it was not independent and was done to varying degrees by people with a stake in the matter," Johnson says, adding that he is not worried about cataclysms, but rather is interested in the legal puzzle. "That's what makes it so interesting for me from a legal standpoint: How courts and lawyers are supposed to deal with this."

The philosophical issue also remains, for it's essentially impossible to prove a negative. How can one prove that a natural cosmic ray hitting Earth every day would not obliterate the planet tomorrow? The same applies to the LHC's particles, but at a certain point we have to abandon the "what if everything we know about physics is wrong?" argument and look forward to the astounding discoveries that the LHC might soon deliver. The collider will run at full power in early 2015.

"Even though it sounds like it should be a scary thing to say," says Lincoln of Fermilab, "yes, I would like to see black holes form." He looks forward to the groundbreaking discoveries of the 21st century. "Whatever we find—and I really hope we find five outlandish things, whatever they are—it's not dangerous."

Science writer ERIK VANCE is based in Mexico City and has written for *Discover*, *Harper's Magazine*, and *The New York Times*. He's afraid of spiders, lightning, and really big fish. But not black holes.

Their Giant Steps to a Cure

Battling a rare form of muscular dystrophy, a family finds an activist leader, and hope

BY JUDE ISABELLA

IN 2007, AT HER high school graduation in Quesnel, British Columbia, Ivana Topic stood at the top of the auditorium stairs, her long gown skimming the floor, her dark brown hair spilling over her shoulders. She had on ridiculously high heels. As she eased down the stairs, very slowly, she hung on to her date. She was afraid her knees would collapse, as her muscles were weak for her age.

From the audience, Ivana's mother, Marijana, watched her daughter's every step, silently panicking and breaking into a sweat. She knew Ivana could easily tumble down the stairs and break a limb. The year before, Ivana had been diagnosed with muscular dystrophy, an incurable genetic disease characterized by progressive weakening of the muscles. Antonia, Ivana's younger sister by five years, was later diagnosed with the same disease.

Around the time of Ivana's graduation, the Topics, an unassuming family originally from Croatia, had begun adjusting their lives as best they could, inquiring about ramps everywhere they went, avoiding walking in snow and sleet. For years, Ivana and Antonia had been subjected to endless medical tests. In 2010, they learned they had a rare form of muscular dystrophy, calpainopathy, which affects about 1 in 200,000 people. The diagnosis meant both would likely be bound to wheelchairs while they were still young women.

Today, Ivana is 24. In May, she graduated from college with a bachelor's degree in finance and general business. She still walks up stairs in her house; her bedroom is upstairs. "I'm definitely a fighter, and will try and walk for as long as I can," she says. "When I notice I'm falling a lot, when I need help a lot, I will go in a chair."

Muscular dystrophy treatment is limited to only palliative medications and therapies. Ivana herself practices yoga. While researchers worldwide are working on lasting cures for muscular dystrophy (funded in part by the famous Jerry Lewis Telethons), rare forms like calpainopathy are "orphans," with only a fraction of

ILLUSTRATIONS BY ELLEN WEINSTEIN

"I'm definitely a fighter, and will try and walk for as long as I can."

researchers and funds devoted to them. With quiet stoicism, the Topics have accepted that modern medicine may not have a solution for their daughters' disease. Still, says Marijana, "Without hope, there's no life."

Following a current grassroots trend in medicine, many individuals with orphan diseases do not wait for the medical industry to care about them. Facing long odds, they are forced to raise money to find a potential cure themselves. But the Topics live by modest means. Marijana runs a daycare center and her husband and the childrens' father, Niko, works for a lumber company. They are in no position to mount a quest.

But then there's Michele Wrubel, 49, a stay-at-home parent from Connecticut who has calpainopathy. For years, Wrubel has been a passionate crusader for a cure. Affluent and well connected, she doesn't varnish the truth about what it has taken to make the medical industry pay attention to her. "To make a difference in this disease, you need money and meetings," she says. "Researchers are not going to study a disease unless there's money behind it to fund the research." For the Topics, Wrubel may be their best hope.

THE GLOBAL GENES PROJECT, an advocacy group, estimates 350 million people suffer from orphan diseases worldwide. Most rare diseases are genetic and tend to appear early in life. About 30 percent of children who have them die before reaching their fifth birthday. The rest battle their conditions throughout life, as most orphan diseases have no cure. Out of the 7,000 orphan diseases identified to date, with about 250 new ones added annually, less than 400 can be treated therapeutically.

This year the European Commission gave 144 million euros to develop 200 new therapies and the National Institute of Health allocated $3.5 billion to research orphan diseases. Yet some diseases are so rare that they remain stepchildren even among orphans. As a result, they receive little research attention and funding. Neither do they fit the list of billable insurance procedures. There's no standard healthcare path to diagnosis, let alone treatment. Similar to the Topics, many patients go through an ordeal, which Marijana describes as "a blur," only to find out that medicine can't help them.

Orphan disease organizations, such as the National Organization for Rare Disorders and the Rare Disease Foundation, encourage patients to take matters into their own hands. "Families have to advocate," says Isabel Jordan, chair of the Rare Disease Foundation. She encourages patients to form organizations, find new methods of funding, and push for research.

"Push for research" could be Michele Wrubel's calling card. She was diagnosed with muscular dystrophy in her mid-20s. But even though calpainopathy was identified nearly 20 years ago—about the same time Wrubel got her initial diagnosis—it took almost the entire second half of her life to determine that she was afflicted with calpainopathy. There were no clinical procedures that would lead to a diagnosis.

"It took a really long time and a very concerted effort," says Wrubel, who walks with canes, submitting to a wheelchair for long trips or when in crowded places. "If you don't know what you're looking for, they don't know what to tell you or how to help you," she says.

In 2008, gene sequencing came of age, which aided physicians in diagnosing muscular dystrophy subtypes. That year, Wrubel's husband, Lee, who holds a medical degree and a master's in public health from Tufts, an MBA from Columbia University, and is a venture capitalist in the medical field, tracked down a neurologist to sequence his wife's genomes. He paid several

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In the quest for a cure, she says, "It's a matter of patients taking charge of their diagnosis."

thousand dollars from his own pocket to learn his wife had calpainopathy.

The Topics had no such luxury. But they did have luck. Cornelius Boerkoel, a clinical geneticist at the University of British Columbia, enrolled the Topics in one of his studies, and so they didn't have to pay to have each of the family member's genomes sequenced. The genome tests gave Ivana and Antonia the bad news about calpainopathy. Their younger brother, Mario, is free of the disease.

Scientists classify calpainopathy, or "calpain," as a limb-girdle muscular dystrophy Type 2a, caused by a mutation in the gene calpain 3, predominantly expressed in skeletal muscle. Those who suffer from Type 2a, such as Wrubel, Ivana, and Antonia, generally exhibit weak hip flexors—muscles that lift up the thigh. The weak flexors give them an awkward gait; they swing their legs forward, landing on their toes, and then sometimes on the sides or soles of their feet. Some walk only on the balls of their feet. The upper body muscle weakness creates abnormally prominent shoulder blades.

Melissa Spencer from the University of California, Los Angeles, who has studied calpainopathy for 14 years, explains that the disease contains many subtypes. The problem with Type 2a, she says, "was a really strange gene mutation that was completely inexplicable." She says it has been a hard disease to study, partially because the implicated protein is unstable and partially because it was a rarity among the orphan diseases. When it comes to funding, calpainopathy has been overshadowed by other forms of muscular dystrophy. "Muscle studies have been underfunded forever and certainly a rare disease like 2a especially underfunded," Spencer says.

In 2010, Wrubel formed the nonprofit Coalition to Cure Calpain 3. In the quest for a cure, she says, "It's a matter of patients taking charge of their diagnosis." She reached out to other sufferers via Facebook, and some donated money. She partnered up with two other nonprofits that had raised funds on their own, both started by those afflicted with Type 2a. So far Wrubel's efforts have gathered close to half a million dollars. With that money, she has funded a project with Louis Kunkel, professor of genetics and pediatrics at Boston Children's Hospital, one of the nation's key muscular dystrophy researchers.

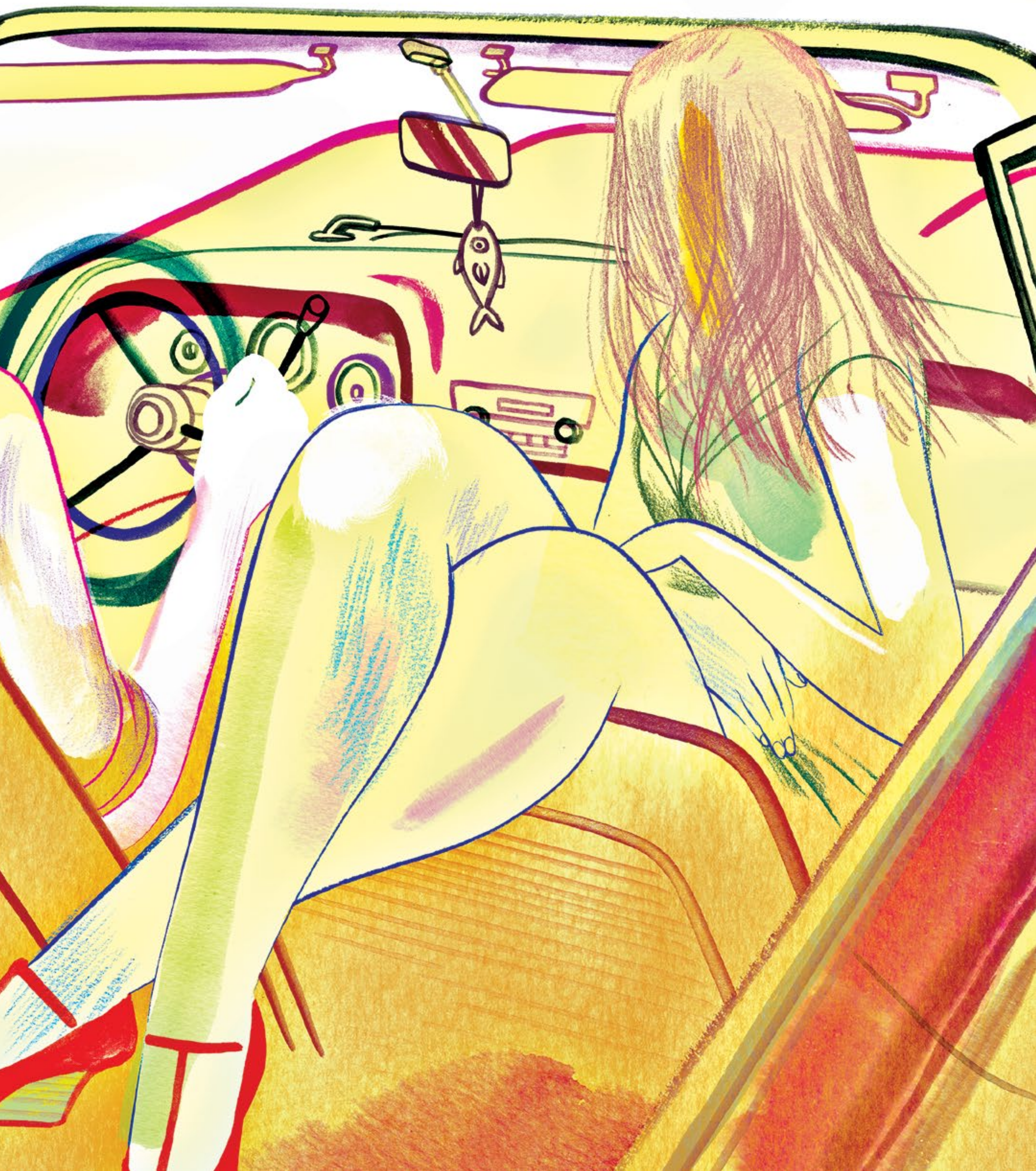
Her coalition also organized a conference to bring calpainopathy researchers together, including Spencer. Years earlier, in 2005, Spencer made a significant breakthrough. She discovered that calpainopathy, unlike more common forms of muscular dystrophy, was not a weakening of the muscle but a growth problem—muscle forms, but fails to grow because of a missing protein. It is different from other muscular dystrophies in which the lack of the protein complex, dystrophin, damages muscle membranes. "With calpainopathy, the muscles lack the growth signal," she says. "It's not transmitted properly." That difference makes a drug cure more possible. "I think this is going to be the easiest muscular dystrophy to cure," she says.

Encouraged by the promise, the Coalition to Cure Calpain 3 gave Spencer's lab a $260,000 grant to investigate how to circumvent the signaling problem and come up with a drug to fix it. But because the United States Food and Drug Administration already has a library of approved compounds that stimulate cell growth in muscle, Spencer's team may arrive at a solution sooner. With the help of the coalition's money, her lab is now plowing through the thousands of existing compounds, choosing those fit for testing. "I think it will be five years before we start thinking about clinical trials," Spencer says—and then another five years before the drugs can be commercially available, she estimates.

Wrubel's coalition intends to get pharmaceutical companies interested, too. "Many pharmaceutical companies see treating orphan diseases as a way to increase profits," Wrubel says. Her husband, Lee, adds, "The whole model for big pharmaceutical companies going forward is different. There is too little in the big pharmaceutical pipeline, and they're looking to feed that beast as much as possible." A 2012 Thomson Reuters study found that drug companies stand to profit from orphan drugs because, compared to drugs for common afflictions, they often have shorter and less expensive clinical trials, with more success. Spencer says a drug for calpainopathy, for instance, would also be useful for patients with Lou Gehrig's Disease and bed rest patients, as it would help arrest the loss of bone and muscle mass. Wrubel hopes to bring Cydan Development, a venture-capital backed orphan drug developer, to their upcoming fall conference in the Netherlands.

As for the Topics, they were excited to learn about Wrubel from *Nautilus*. Ivana recently connected with Wrubel through Facebook. "I only talked with her a little bit, but she seems ambitious and driven," Ivana says. "Definitely not someone who is going to sit around and wait for something to happen. Definitely inspiring. And the possibility that something might help in any way is a good thing to hear, for sure." Ivana says she now wants to get involved and advocate for her own disease. "I definitely want to do something," she says, and Wrubel's coalition "would be a good place to start."

JUDE ISABELLA is a science writer based in Victoria, British Columbia. Her new book, *Salmon, A Scientific Memoir*, will be released next year.



Hardly Never in Vegas

Fat Johnny Little and Salty Salt Sue make a break for the desert

BY CAMILLE ALEXA

ILLUSTRATIONS BY ANGIE WANG

S**ALTY SALT SUE MET** Fat Johnny Little at a card game so hot it burned a girl, the sultry Louisiana night dampening her clothes, making her tingle from the waist down. She sat next to Vinnie DeLuca, who bore a passing resemblance to Dillinger—his pencil moustache and fancy cigar and straight flush minus one—with her knee crooked over the arm of his chair like she could keep her legs anchored solid that way, keep everything from going south.

Going south was what she was doing, of course. Had been, all the way from Quebec farm country, leaving behind the rippling acres of corn and barley, the damp, whispering rustle of unbaled hay, heading for the desert from one man's bed to the next until they all looked the same, both the men and the beds. All the way from Canada, and she'd made it only as far as Louisiana swampland.

So here she was in a roomful of small-timers, boys playing men who only heard about real mobsters on the radio, who muttered long-dead gangsters' names like the litany singsong of prayer: *Baby Face Nelson*, *Ma Barker*, *Bonnie Parker*, *Clyde Barrow*. They *toted iron* to card parties and *bet on the bangtails*, and talked about *the big house* like they'd done real time, though Vinnie DeLuca had never been north of Tennessee. He'd been named Vincent by his cold northern father and his warm Cajun mother, who pronounced it like she had marbles in her mouth: *Van-sawhn*. Sometimes Vinnie took a page out of his dead daddy's book and hit his women. He thought it proved he was tough, a real public enemy, but Salt Sue thought it proved he was mean.

That night, as the humidity got to her at last and she felt that dreaded shimmer below the waist—soft, almost rubbery behind the kneecaps like undercooked yolks—she excused herself from the poker table and stumbled to the powder room, her legs already forgetting what they were just from the moisture in the air. Tears welled over in her eyes and left black mascara streaks as she fumbled with the doorknob and let herself into the john. At least tears and sweat were saltwater, or she'd have been a goner for sure. Sold by the boys to some traveling circus as a freak, maybe. Or maybe just lynched, strung up, and hung out to rot in the moist southern night like those poor Yankee boys over in Shreveport, who just wanted it so everybody got treated the same regardless of the color of their skin.

A light knock came at the door. Sue scrubbed her eyes with trembling fingers. "Go away," she said, adjusting her garter strap, reassuring herself by touching her own thigh, feeling its roundness, its solidity, the smoothness of skin rather than scales beneath the satin and hooks. "I don't feel so good."

It was Vinnie, his voice heavy with frustration and owed apology—thousands of owed apologies, but most especially this one. "You got to come out," he said, francophone roots not weighing down his southern accent the way they sometimes tinted her northern one. "I done lost you in a card game to that skinny fella on his way to that town the millionaire done rebuilt. That town with all them lights and the legal gambling, way out in the middle of the goddamned desert. Dang..." His anger was at

She excused herself from the poker table and stumbled to the powder room, her legs already forgetting what they were just from the moisture in the air.

losing cards, not at losing her. "Dang..."

A few heartbeats passed before Sue threw open the door. "Desert?" she said, but he was already gone.

Just the thought of dry air cleared her head, made her stand straighter. She wobbled only slightly as she ran down the hall to lurch into the smoky room where the boys were scooping up cards and coins and strapping their guns back on beneath black pinstriped vests over white cotton undershirts. She looked around the room, clinging to the back of a chair for support as salty sweat gathered under her arms, rolled down the collar of her dress between her breasts.

"Desert?" she said again. "I'm going to the desert?"

Fat Johnny Little scooted his chair back, tipped his hat at her like a gentleman. "Yes, ma'am," he said, removing his toothpick with one hand, smoothing his slicked-down hair with the other. "If'n you want to. A place called Las Vegas."

THEY DROVE ALL NIGHT, Sue at first grateful for the top folded down on his convertible, black wind whipping around them, keeping moisture from settling on her skin like poison. But eventually, as always, she started to worry about rain.

"It ever rain where we're going?" she asked, squinting up into squid-ink darkness, raising her voice above the rumble of engine, of tires on hot night road.

"Hardly never in Vegas, ma'am," he said, the first words he'd spoken since she'd thrown her battered carpet bag in the back seat of his bran' new 1966 red convertible car and they'd squealed out of Vinnie's mother's driveway, gravel spraying behind them like ocean froth off a wave. "Hardly never rains in Vegas," he repeated. "Convertible makes sense in a place like that. Good investment."

"Good poker playing, I think you mean," she said, and he smiled without looking at her. Boys and their cars, she'd never understand. But the desert... the desert... "No rain?" she asked again, wind grabbing her words, tossing them out onto the long ribbon of freeway behind them.

"Hardly never."

"How 'bout guns?" She was less afraid of guns than of rain, but thought she should ask.

The reflected glow of headlights flickered up onto his face, casting it into choppy black and white like an old silent film. "There's guns," he said, watching the road. "But Mister Hughes is working to change all that. He's been real good for that town. I figure I'm going out there to work for him."

She studied him by the cinematic flickerlight, his long frame impossibly skinny, his brilliantined head oddly naked without the oval brim of his hat. "Are you muscle, Mister Little?" she asked. "Are you like Vinnie and those boys, like to push a girl around? Like to carry guns? Thinking maybe they're wiseguys or something? Just what kind of work you plan to do for this strange Mister Hughes, who makes so much money, who the

magazines say steps out with pretty movie stars, who's supposedly been so good for a desert town hardly anybody ever heard of until he decides to make it heard of?"

Fat Johnny's hands tightened on the wheel as she talked. The knobs of his knuckles glowed starkly, each joint white against the black grip, against the blacker night beyond the windshield. "No, ma'am," he said, staring straight ahead at the road. "I'm not muscle; I don't do dirty work for nobody. Not even a Mister Howard Hughes."

He glanced at her then, expression nervous, but also almost laughing at himself, hands relaxed on the wheel. Looking at her sideways, he said, "I'm an accountant. Seems I'm good with numbers. Self-taught."

And for some reason it was funny. Even though Salt Sue had just been lost in a poker game—passed from one fella to another like she had been since she was sixteen and her père sent her off with a north-ranging Fuller Brush man who wasn't too proud to be seen with a scrawny little farm-country thing who refused to bathe in good clean water like decent folks—even though all that, Sue laughed.

They both laughed. Laughed till they cried salt tears. Fat Johnny had to pull to the side of the road, easing his big candy-shine convertible into the parking lot of an abandoned Navajo souvenir stand at the edge of one of that American President Eisenhower's Interstate Highways some place in New Mexico. They sat on the cooling hood of his car and ate hardboiled eggs as the sun crested lavender over distant mountains like Sue had never seen, so crisp and clear was the air.

"Good to see you laugh," he said, pouring her the first cup of coffee from his Thermos into the cup lid and handing it to her like a gentleman, before his lips had even touched the rim. "I watched you all night at that card table back there. It pretty-near killed me to see a person looking so sad."

"And so you won me in a poker game."

"And so I did."

Eventually, as always, she started to worry about rain.

Fat Johnny had the good manners to look ashamed, but there was a defiant set to his narrow chin that made Sue smile. “Did you cheat, Mister Good-with-numbers?”

He stared hard at her a moment. When boys thought they were bigger than guns, cheating got them killed. Sue had seen it more than once, and by the look in Fat Johnny’s eyes, so had he.

“I did,” he said. “I cheated. And I won you in a card game.”

She handed him back his Thermos cup, empty, with a lipstick stain red against its green aluminum rim. “Won me to do what with, Mister Little?”

He looked self-conscious again, suddenly taller and even thinner than before. His belt pulled tight around his waist; there were no notches beyond the one he used. His shirt hung from his shoulders like it was draped over a wooden hanger, and in the early morning light, in the abandoned gravel parking lot of the closed tourist souvenir shop—a plywood teepee with peeling paint in the vague outlines of animals—he looked gaunt, skeletal, and very, very young.

“To set free,” he said.

THEY DROVE ALL THAT day too, the sun hard and bright against Salt Sue’s cheeks, the dry air making her skin feel tight, making her lips chapped even under her thick dimestore lipstick. Not much peace for talking, what with the constant wind and the awkwardness building up between them with the miles. At roadside diners where they stopped along the highway—she unceremoniously letting him pay for everything since she had no money, had never had any money—he couldn’t get enough water. Big glasses of it, tall and sweating from the ice inside. She shuddered, and scooted far to her side of the table, upending the salt shaker into her glass until the granules swirled inside against her spoon like snowflakes in a souvenir globe from a state fair.

He shook his head. "I never seen nobody put salt into fresh, clean water to drink," he said, at least two or three times, until she answered.

"I can't drink it straight," she said. "I'm allergic, if I get too much."

He frowned. "But you drink coffee. You drink gin, and eat fruit." He pointed to her hard china bowl of wilted brown-tinged strawberries. "That's the same as drinking water."

Sue dumped another teaspoonful of salt into her glass. "*Non*," she said. "No, sir, it is not."

"Don't you go swimming?"

"Never."

"How do you..." His voice dropped, and he slid a glance sideways at the waitress walking by with a slice of pie for somebody else. "How do you take a bath?"

She shrugged. "I most often did not, 'til I was sixteen. Then I discovered the salt trick. Salt, it is cheap. And the saltwater, it does not aggravate my condition."

"Well, then." He leaned back against the red vinyl of the booth behind him. "I guess I see where you got your name."

Salt Sue took just a tiny sip of her water, as though to drink more would negate the powers of the concoction's salinity. "I guess you do," she said.

As they left the diner, she placed a hand on his arm. It was the first either of them had deliberately touched the other. "Mister Little..."

He stood still under her fingers, so skinny she could practically feel the bone of his arm through his sleeve, as though there was no intervening flesh or fat or muscle or skin between her hand and his skeleton. "Yes?"

"Thank you for getting me out of that swamp. The humidity, the water so heavy in the air, on the skin, rolling off the body... That place, it nearly killed me."

He nodded. "Me too. And please, call me Johnny."

She tilted her head. "Not Fat Johnny? That's what Vinnie calls you. That's what everybody calls you, back there."

He looked away, looked at the asphalt unfurling from the diner parking lot across the scrub and the reddish pebbles as far as they could see. "Yes, ma'am. I thought I might just be Johnny in the new town, though. Thought I might start with you."

She squinted up at him. "I'd like that," she said. "Back home, my Maman, before she died, called me Suzette. But here I am Sue. You should call me that. Call me Sue."

He nodded, as though a bargain had been struck. "I reckon I will, then."

"Yes," she agreed. "I reckon you will."

NO SETTING SUN COULD compete with the lights of Las Vegas. Mister Hughes had breathed life into the stillborn town, lit up everything brighter than Christmas. Brighter than 20 Christmases all in a row, visible, clear as daylight, from a mile away.

Clouds, too, were visible on the horizon. Dark, heavy clouds rolling in

He watched, frozen by the sight of her as she writhed on the seat beside him.

to obscure the setting sun, to turn its orange rays red, fading to grey. The first drops fell as they passed the outskirt motel, with its kidney-bean pool and wrought iron rails painted hot pink plastic to match the hollow lawn flamingos thrusting up from cracked dirt by the roadside.

Salt Sue sank low in her seat, trying to screw herself up tight against the falling drops. "No rain," she said, salt tears tracing down her cheeks, each chasing the next. "No rain in the desert, you said."

Fat Johnny Little pulled to the side of the road, left the engine idling, helpless in the face of her misery. "It's okay," he repeated like a mantra, like a misbehaved schoolboy left to write something a hundred times or face the paddle. "It's okay. It's okay."

Panic painted her face in stark flushed hues. "Put the top up!" she cried, eyes wilder than a horse's in a barn fire. She beat her balled-up fists against the folded convertible top, pretty and white-pleated and smelling of new rubber. "*Put the top up!*"

He watched, frozen by the sight of her as she writhed on the seat beside him, raindrops fat with un-desertlike moisture splattering onto her cheeks, her hair, the thin ridges of her clavicles where they angled from the scooped neck of her hand-me-down dress. "*It's okay*," he murmured, wrapping his arms around her; "*It's okay*," while her legs lengthened, merged into one.

As her legs stiffened the rest of her softened, like wax running down the side of a candle. She became like melting butter in his arms, flowing toward the floorboards of his candy colored bran' new 1966 convertible bought off the lot with hard-won money. He held her as she changed, as her body shifted, as her tail grew, fusing together where her feet had been.

Freshwater rain slid down her cheeks to mingle with saltwater tears. "It's supposed to never rain in the desert," she sobbed. From the waist up she was still a girl, farm-country raw and whiplash thin, with huge round eyes and a permanent downward twist to the corners of her mouth. Below the waist, she was something else.

"Not *never*," he said, her despair like a knife to his ribs. "Rarely. Hardly ever. But not *never*."

She cried and he let her. The rain blew over as quickly as it had blown in, dissipating on the final rays of red sun where it dipped below the sand. A few minutes was all; a few minutes between a secret, and a secret revealed.

But he didn't let go. She dried her tears, listening to the sound of water soaking into hot thirsty desert ground, soaking until it was gone. "I come all the way from the north," she said. "I come all this way for a beginning. And now it's over before it even can start. Ended. Fini."

Fat Johnny Little—just Johnny now, if he had his druthers—watched her tail, vivid and scaled, flap against the red vinyl seat of his shiny new car. On the floorboards, pushed off by the realignment of flesh and bone, lay her shoes, red buckle t-straps with a sloping wedge heel. Beside those fluttered her shredded nylons, and a garter belt he'd only glimpsed back in Louisiana, where he'd blushed and looked quickly away without her noticing. Her skirt rucked up about her hips where she'd slid down in her seat, the lower half of her body not accommodating an upright position better suited to hips and to thighs than to scales and fins.

From his awkward angle, he smoothed away the rivulets of rainwater running from her hair, the saltwater from her eyes. "Nah," he said, self-conscious, trying not to think about how he looked so close up, how deep his ocular sockets, how unnaturally sharp and bony the planes of his face. He was certain his teeth, when he smiled, stuck out like broken piano keys. "Nah," he said again. "It ain't over. It's just beginning. Agreed?"

When she lunged up and kissed him it was a surprise, though not unwelcome. He heard the wet slap of her tail against his floorboards and glanced down in time to see her legs reform as the last raindrops evaporated into the dry desert air off her scales, off her skin.

Her fingers, light in his, were tiny and soft. "Agreed, Sue?" he asked again, and remembered to breathe.

In the fading light he made out the shape of her smile, off-kilter and unpracticed. "Agreed, Johnny," she said, and reached to straighten her skirt with one hand, not letting go of his hand with the other.

CAMILLE ALEXA'S short fiction has appeared in many magazines and anthologies. She is the author of a short story collection, *Push of the Sky*, which was nominated for the Endeavour Award.

05

THE PHILOSOPHER DANIEL DENNETT has long described consciousness as "fame in the brain." He believes different representations of reality compete with one another at a subconscious level, and conscious perception begins when one representation wins. It's a surprising concept. And one that provoked us to look more carefully at fame itself.

What we found is that fame is far more than empty pursuit or idle distraction. It is a proper category of natural phenomena. For example, isn't evolution a race among genes for dominance? And what about the development of languages, or the formation of cities, or scientific peer review? When we looked, we found competition among agents and representations in every direction. Winner take all.

From *Forbes* lists to Facebook, we have used science and technology to move fame from surmise to spreadsheet. The result is a different kind of creature than we are used to, crouching among networks and equations. So framed, fame deserves our attention.

Welcome to "Fame."

—MS

"The medium may have changed from Homer to Twitter and texting, but the message is the same."

TOM PAYNE
"Drop-Dead Famous" p. 140

Fame

THE EVOLUTION OF CELEBRITY


T. Walenta

On the Origin of Celebrity

Why Julia Roberts rules our world

BY ROBERT SAPOLSKY

I **HAD *SUCH* FUN THE OTHER EVENING.** LeBron James, Anne Hathaway, J.K. Rowling, and I had gone ice skating in Central Park. My dear friend Koko the sign-language gorilla was there, ice-dancing with Ryan Gosling, who is always good for a laugh. Afterward, we all got hot chocolate and ran into Lady Gaga and Freeman Dyson, who had just flown in from Cabo. Koko and Ryan had a hilarious arm-wrestling contest (we called it a draw). Things got even crazier when we went to get sushi and met up with Hillary Clinton, Justin Bieber, and Lucy the *Australophithecus*. Eventually, we all wound up at Hil's apartment, where we played Twister half the night. What fun.

Now who wouldn't want an evening like that?

ILLUSTRATIONS BY TOMASZ WALENTA

We all feel the magnetic pull of celebrities—we track them, know their net worth, their tastes in furniture, the absurd names of their pets and children. We go under the knives of cosmetic surgeons to look like them. We feel personal connections with them, are let down by their moral failings, care about their tragedies. As I write, my family of musical fanatics is mourning the death of Cory Monteith. We not only feel for the pointless loss of a talented young actor, and for his girlfriend, Lea Michele, but in some confused, inchoate way, also feel heartbroken for Finn and Rachel, their characters on *Glee*.

Why the obsession? Because we're primates with vested interests in tracking social hierarchies and patterns of social affiliation. Celebrities provide our primate minds with stimulating gyrations of hierarchy and affiliation (who is sleeping with, feuding with, out-earning whom). Celebrities also reflect the peculiar distance we have traveled culturally since our hominid past, and reveal how distorted our minds can become in our virtual world. We obsess over celebrities because, for better or worse, we feel a deep personal sense of connection with people who aren't real.

FOR ALL PRIMATES, NO matter how rich the ecosystem, resources are finite and competition can be fierce. Numerous primate species have evolved dominance hierarchies that ritualize unequal resource distribution. Take savanna baboons, a species I have studied in Africa for 30 years. They live in groups of dozens of animals, and the most defining fact of life for a baboon is his or her rank in a sex-specific dominance hierarchy. Social status is always on a baboon's mind. Even when going about their daily business, baboons are frequently glancing at dominant individuals.

Why is rank so important to a baboon? For one thing, a stable dominance system is a huge social convenience—it insures bloody teeth and claws don't appear each time a potential conflict arises. Instead, everyone knows his or her place, and if, say, something to eat is discovered, a dominant individual typically needs to do nothing more than glare at a subordinate to get the prize. The dominance ranking system also influences who a baboon mates with, whose genes are going to be passed on in their offspring. It greatly influences who a baboon will form a coalitional partnership with. After all, who'd you want to have your back in

Who'd you want to have your back in a fight: the schlub of a low-ranking baboon snoozing by the bushes, or the alpha male who's been on the cover of Baboon *magazine?*

a fight: the schlub of a low-ranking baboon snoozing by the bushes, or the alpha male who's been on the cover of *Baboon* magazine?

Humans don't have the strict dominance hierarchies seen in baboons. For one thing, we simultaneously belong to multiple hierarchies and most value the hierarchy in which we rank highest (think of the lowly clerk in a corporation who captains the company softball team). Still, over the course of human evolution, assessing social dominance and subordinance has been a ubiquitous feature of our interactions; it's deep-set in our brains. In a study by Nicholas Rule, a University of Toronto psychology professor, subjects viewed pictures of faces with either stereotypically high- or low-status expressions. People could correctly identify the status even when viewing pictures for 40 milliseconds. That's *40-thousandths* of a second.

Ten-month-olds are already attuned to dominance, as shown in a cool study by Lotte Thomsen of Harvard. On a computer screen, a big square and little square independently move from one side of the screen to the other. To tap into the infant's social brain, the squares have eyes and a mouth—they're personified, they *want* to get to the other side. At some point, they come from opposite sides and head straight toward each other—they're going to bump! Will one of them give way? Infants look more intently at this scenario than when the squares don't get in each other's way—social conflict is interesting. Half the time it would be the little square which would lie down and give way to the big one, half the time the big one would give way. When it's the big square groveling in the dirt submissively, infants look far longer—hey, that guy's supposed to win the interaction, he's bigger. (The study includes subtle controls that show the 10-month-olds are responding to status and not just the fact that big objects exert more physical force on small objects).

Brain-imaging reflects our fascination with dominance relations. When subjects evaluate social status from facial cues, they activate the fanciest, most recently evolved part of the brain, the frontal cortex (more specifically, subregions called the ventrolateral, ventromedial, and dorsolateral prefrontal cortices). These regions are activated when people are figuring out consistent status relations, where Person A always trumps Person B. As shown by Caroline Zink

Some guy in the next valley is proto-famous for his hunting skill, and people in your crowd believe he brings down elephants with his teeth.

of the Lieber Institute for Brain Development, if A and B keep flip-flopping in their relationship, there's also activation of the amygdala, central to processing fear and anxiety. We're unsettled if we're not sure who in our social world gets ulcers and who gives them. We seem to need to be clear about social hierarchy for our well-being.

Primate brains, in fact, developed in relation to social activity. Anthropologist Robin Dunbar has shown a correlation exists between the average size of the neocortex and the average size of a primate's social group. In other words, big neocortexes and the ability to keep track of numerous dominance relations evolved hand-in-hand.

SO WE THINK A LOT about status relations, and bring considerable neural firepower to the task. That's part of our primate legacy. It's only natural, then, that we see celebrities in terms of social status and rank them, given their fame, as high-status individuals, and we their subordinates. On the savanna, the high-ranking baboon draws other baboons' glances. In the supermarket checkout line, the celebrity grabs our attention.

But fame and high status are not always synonymous. The latter is about the real world, how we interact with people at the water hole or water cooler. In contrast, with rare exceptions, we don't interact with the famous; instead, they dwell on another planet. That difference goes a long way toward explaining why our brains do all sorts of distortive things with celebrities. Without face-to-face feedback in a community—reality testing—our compass drifts.

In the hunter-gatherer world, which constitutes 99 percent of human history, the difference between status and fame was fairly benign. Some guy in the next valley is proto-famous for his hunting skill, and people in your crowd believe he brings down elephants with his teeth, while the reality is that he's merely awesomely accurate with a spear. But in modern life, the famous are even more detached from our everyday realities. On the most mundane level, they can be more physically distant than the next valley—if you're the right kind of *Guinness Book of World Records* fanatic, the guy in India with the 14-foot-long mustache may count as famous.

Modern life also provides more realms of expertise for potential fame. For our hunter-gatherer ancestors, somebody might have a good rep for hunting or making obsidian blades, painting on cave walls or leading awesome shamanistic ceremonies. But now people can gain fame by being as rich as The Donald, bending it like Beckham, belting like Adele, or by figuring out something like special relativity, which to most people sounds like something that *did* come from another planet.

Moreover, you can have fame in our contemporary world (at least for 15 minutes) for bizarre things unrelated to expertise. You can be famous for being famous, like Paris Hilton, for being the Numa Numa guy lip-syncing a song on YouTube, or for having sex with someone famous. (Wait, has history decided if that was indeed sex that Monica had with Bill?) You can attain fame as the incoherent houseguest Kato Kaelin, or by having your penis cut off by a vengeful wife (remember John Wayne Bobbitt?).

What do we get out of our obsessions with the famous? Sometimes it's inspiration and emulation. There's a time-honored logic to this. Just as you could have improved your obsidian blade-making technique by watching a master spear maker, one's contemporary life might be miraculously transformed by picking up fashion tips from Angelina and Brad.

BUT THERE ARE LESS rational things that drive the obsessiveness, ways in which our hunter-gatherer brains do garbled things with these weird, modern niches of fame, where we invest our real needs in unreal people. A major one is the strange fantasy world that

PHOTO BY CLIFFORD O'LEARY

celebrities inhabit in our heads, where we imagine ourselves affiliated with people we will never know, where we feel like they'd cover our backs during a squabble over meat from the antelope hunt. Our personal status is raised by real relationships with high-status individuals, and it can be an intensely pleasurable event. The incandescence of high status is such that our brains have a tough time realizing our relationship with celebrities is only pretend. Evolution hasn't had time to tell us the high-status individuals who stir our emotions are make-believe.

In the movie *Notting Hill*, Julia Roberts plays the mega-movie star, Anna Scott, who through the usual implausible twists of fate of the movies, falls for a meek nebbish bookstore owner, played by Hugh Grant. He brings her to a birthday party for his sister, who knows nothing about this unlikely development in his life. The sister arrives and discovers that her brother has brought … ANNA SCOTT! "Oh holy fuck!" the sister exclaims, hyperventilating, "This is one of the key moments in life when it's possible you can be really genuinely cool, and I'm going to fail just 100 percent. I absolutely, totally, and utterly adore you and I just think you are the most beautiful woman in the world. And more importantly, I genuinely believe, and I've believed for some time now, that, that, we could be best friends."

We literally view those with high status as bigger than life. A 2009 study led by Georgetown psychology professor Abigail A. Marsh shows that people who express dominance are perceived as being taller than they are. And we overgeneralize the expertise of the famous. Actors who play doctors get asked for medical advice. Dennis Rodman discusses Korean geopolitics, Tom Cruise spouts Scientology drivel about the sins of psychiatry, and Jenny McCarthy, whose fame comes more from her *Playboy* appearances than from her epidemiology training, convinces people to not vaccinate their babies because of pseudoscience about autism. People have probably *died* because of that.

Arguably the most distortive thing we do with the fame of celebrities is feel diminished by them. It's a threat to our social standing, desirability, and self-esteem if the person next door not only looks better than you, but if on top of that, his goat looks better than yours. We know these people are the creations of personal reps, ghostwriters, publicity agents, and the Botox-industrial complex. Yet we look in literal or figurative mirrors and feel less content with who we are.

But we are not without the means to defend ourselves against affronts to our self-worth, and it's a defense as old as language itself—gossip. Anthropologist Christopher Boehm has studied status relations in traditional societies, demonstrating how members of hunter-gatherer bands are fiercely egalitarian, constantly on the lookout for some miscreant who is being domineering in their opinions or hogging food. Gossip plays a key role. It helps for reality testing ("Is it just me, or was he being a total jerk just now?"), passing news ("Two guesses who just happened to get a foot cramp during the scariest part of the hunt today"), and for building consensus ("Something needs to be done about this guy"). Gossip is the weapon of norm enforcement. It makes us feel better when someone who is powerful and unpalatable gets their comeuppance. Justice briefly reigns and for a moment the grass doesn't seem greener on the other side. Neuroimaging studies consistently show that reward areas of the brain glow with satisfaction when we feel *schadenfreude*, when we gloat at the misfortune of someone we envy.

In our innate primate dance with status, gossip momentarily puts us on even footing with the alphas. We may never be as glorious or acclaimed as a celebrity, but at least we know—*OMG, look at this picture!*—that it won't be humiliating front page news if we're ever photographed wearing something *that* hideous. And even if that sort of pleasure is rare, I personally can take daily comfort and a sense of a life well lived in knowing that, if he were to stop and really think about it, George Clooney would have to admit that he considers me his best friend forever.

ROBERT SAPOLSKY is a professor of biology and neurology at Stanford University. He is the author of a number of books, including *Why Zebras Don't Get Ulcers, Monkeyluv,* and *A Primate's Memoir.*

"THE BRAIN ON TRIAL" BY TOMASZ WALENTA


Ryan Berkley

Genes That Won the Fame Game

Discover genes that unite life on earth

BY YVONNE BANG

FAME IS SOMETHING THAT sticks to someone or something, a quality earned or gained perhaps for no reason at all. It is also a force of connection. A famous person or thing forms a hub in a network that binds us all. Genes can also be famous, stars in the parade of the animal kingdom. So what genes are The Beatles of DNA? Genes so famous they unite species around the globe? Given there are 8 million or 100 million probable species on earth—depending on who you ask—it was no easy task to select the Fab Four. But after asking some of the world's top biologists, we settled on our John, Paul, George, and Ringo, known as TP53, CYP51, TAS1R2/TAS1R3, and opsins. Each, over the course of eons, has been critical to the development and health of living creatures.

The graphic on the following pages shows which species share the critical genes. (To see which, match the color bars next to the genes to the bars under the animals and plants.) It is an illustration of life's common bonds: the points where humans, animals, and plants come together.

ILLUSTRATIONS BY RYAN AND LUCY BERKLEY

TP53: SOMATIC CELL PROTECTION

Cell duplication is a fact of life for all multicellular species, but things can go wrong during the process. Environmental stressors like chemicals and radiation can damage DNA, the code that cells utilize to replicate themselves. The TP53 gene codes for the p53 protein—nicknamed the "guardian of the genome"—which ensures duplicating cells faithfully reproduce exact copies of themselves. If the DNA of a cell is damaged, p53's first response is to trigger the repair networks that will maintain the integrity of the genome. But in the face of irreparable damage, it will initiate the cell's death, or apoptosis. Without a guardian like p53, the proliferation of defective cell copies can result in tumors, or other life-endangering situations. Some researchers suggest the evolution of TP53 goes back about a billion years, which means a great number of multicellular organisms utilized this gene as a tool to manage increasing cellular complexity.

CYP51: SYNTHESIS OF CHOLESTEROL

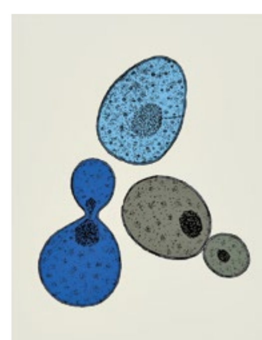
The CYP51 gene exists in all vertebrates, as well as in some plants, fungi, and even various bacterial species. It codes for a protein that plays a small but important role in the synthesis of cholesterol (or ergosterol in fungi and sitosterol in plants), a molecule that helps cell membranes remain fluid and functional. The protein's sole task is to remove a methyl group (a carbon attached to three hydrogens) during the complex and long process of cholesterol production. When the CYP51 protein removes the methyl group, it changes the shape of the cholesterol precursor molecule, making it just the right fit for a cell's membrane.

TAS1R2/TAS1R3: SENSE OF SWEET

Although humans enjoy many a frivolous sweet thing—from cupcakes to ice cream—the detection of sweet is essential for the survival of creatures like the giant panda that require energy-supplying carbohydrates in their system. The TAS1R2 and the TAS1R3 genes code for two proteins that fit together in such a way as to attach to a particular "sweet" molecule. Many organisms, such as elephants and chickens, might just have one gene or the other, but only having both of them will make things taste sweet.

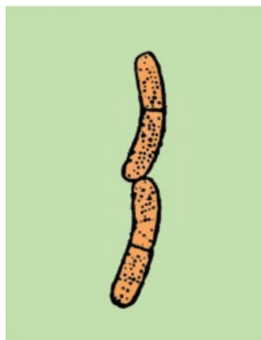
OPSIN GENES: LIGHT DETECTION

Opsin genes code for proteins that embed themselves in the membrane of photoreceptor cells at the back of the eye cup. When the opsin protein is attached to organic chemical called a chromofore, or retinol, or just plain Vitamin A, it becomes part of a pathway for detecting light. When light hits the chromofore, the chemical changes shape, and so does the opsin, setting off a cascade of reactions within the cell that lead to an organism's perception of light. Although only a portion of all species possess the requisite brain power to create images from this information, many less complex creatures, like the box jellyfish, still have the ability to detect light, and use it as a navigational guide or a sensor detecting the presence of both predator and prey.











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T. Walenta

T. Rex Might Be the Thing with Feathers

Behind every famous dinosaur are unsung heroes

BY BRIAN SWITEK

IN 1858, A COLLECTION OF large bones was found in a field in southeastern New Jersey. Today, the site is lost within the unremarkable sprawl of suburban residences, and there is an easy-to-miss plaque that commemorates a 78-million-year-old Cretaceous herbivore called the *Hadrosaurus foulkii*. Unless you're a hardcore dinosaur aficionado or a paleontologist by profession, most likely you have never heard of the *Hadrosaurus*, but this dinosaur is more significant to science than the immediately recognizable *Tyrannosaurus rex*.

The way we imagine dinosaurs has evolved over the three centuries since their discovery. It's an evolution characterized by the forces of fame, for the animals that rivet the public's imagination are not the ones that yield the most interesting information about ancient biology. Stars such as *T. rex*, *Stegosaurus*, and *Triceratops* bask in the glory of public attention while little known dinosaurs such as *Hadrosaurus*, *Deinonychus*, *Maiasaura*, and other unsung species do the heavy lifting of scientific revelation.

The injustice of fame is a common trope in science, but the history of paleontology provides a particularly vivid example, for it is an unusually harsh jury that decides which dinosaurs get memorialized in popular culture. Fond memories of museum trips and sandbox battles between plastic effigies of dinosaurian champions linger long past the "dinosaur phase" of many children. Even as scientists try to retire "*Brontosaurus*" from the canon—because 19th-century confusion resulted in too many dinosaurs named from too few bones—it is still beloved by many, a sign of how hard it is to shake the public's devotion to these creatures.

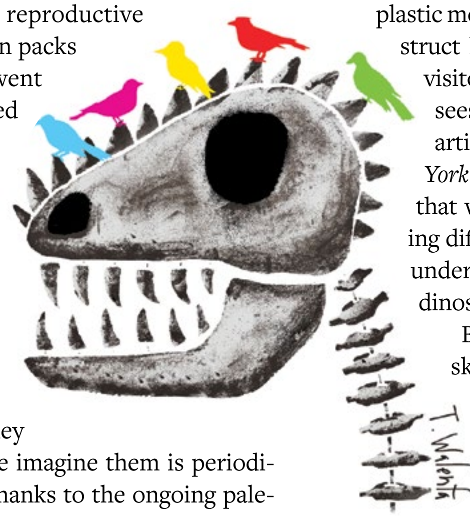
That devotion stretches back to the 18th century, when European naturalists recognized the curious bones found in mining pits and countryside rock outcrops as clues to a past that predated humans. The first guesses as to the size and shape of the owners of these

ILLUSTRATIONS BY TOMASZ WALENTA

If birds evolved from dinosaurs like *Deinonychus*, then dinosaurs survived.

bones conjured up visions of creatures both stupendous and preposterous.

Dinosaurs were first imagined as relatives of fire-breathing dragons, then as the ancestors of lizards, who swept their gigantic tails as they slithered along the ground. They were also portrayed as slothful crocodiles that spent the days in the sun trying to move the needle on their naturally cold-blooded body temperature. However, as more fossils were discovered over the course of the next two centuries, new light was shed on the dimensions of these creatures, as well as on the texture of their outer coat (scaly, armored, or even fuzzy), whether they were meat-eaters or plant-munchers, their reproductive habits, whether they lived in packs or alone, and why some went extinct while others evolved into birds.



In the late 19th and early 20th centuries, several dinosaurs, including *T. rex, Triceratops, Stegosaurus*, and a handful of others, emerged as the celebrities of their species. And while these stars are fixed in the public eye, they are not immutable. How we imagine them is periodically updated and revised thanks to the ongoing paleontological finds that continue to reveal new species. They are paraded around at conferences, receive long Latinate names, and even get their 15 minutes of fame in media headlines. But many dinosaur species fail to exert any real staying power on the public imagination. They pass into obscurity while the valuable information they provide serves to refine and deepen our knowledge of all dinosaur species. We take information gleaned from newly discovered species and slap it back onto the dinosaurs we know and cherish. It's a boon to the brand name dinosaurs that receive regular makeovers and helps them stay relevant.

Such is the trajectory of *Tyrannosaurus rex*, literally the "King of the Tyrant Lizards," which was first described on the basis of an incomplete specimen found in Montana in the early 20th century. Henry Fairfield Osborn, a curator at the American Museum of Natural History (AMNH), named the massive carnivore in 1905. The following year, the museum began to construct the mounted skeleton that still draws visitors to the fourth floor exhibits. When only the legs of the enormous theropod were erected, *The New York Times* proclaimed *T. rex* the "prize-fighter of antiquity," and wrote that the hundreds of thousands of schoolchildren who poured into the museum would now have "a larger outlook into the future of a world that has such a past." *T. rex* became a bridge to the past.

And the reign of *T. rex* has continued unabated. In 1937, the doors of the Dinosaur Park in Rapid City, S.D. were opened as part of a New Deal initiative. An 80-foot plastic model that took 14 men 15 months to construct looked down on tens of thousands of visitors just in the first year. Today, the park sees upwards of 120,000 per year. In an article about the park's opening, *The New York Times* ran pictures of the star dinosaurs that were on display, which showed a striking difference to how we see them today and underscoring how much our image of the dinosaur evolved in the past seven decades.

But even with two relatively complete skeletons collected for the AMNH by professional fossil hunter Barnum Brown, the details of what *T. rex* was truly like eluded experts. Contributions from the British anatomist Richard Owen (who coined the term "dinosaur" in 1842) established a set of characteristics that differed drastically from those that had come before. Naturalists had previously assumed that the ratio between jaw and body size was the same for dinosaurs and crocodiles. This resulted in an impressively large lizard of more than 100 feet who dragged its enormous torso along the ground. Owen revised the image of the giant lizard and cut the size of the dinosaur down to about 40 feet. He envisioned a creature that had the hide of scaly reptiles but an upright posture, like that of a rhinoceros or an elephant. But even Owen's conception was not to last.

It was displaced by the discovery of *Hadrosaurus*, that little-feted New Jersey native. This creature was significant because, unlike dinosaur specimens found in Europe, the recovered bits of backbone, limbs, hip, *What made this creature fascinating was what covered its tiny frame. Instead of scales, its coat was a mane of filamentous feathers running along its back.*

and skull came from a single individual. With the full skeleton, experts were able to see that the forelimbs of the dinosaur were significantly shorter than the hind limbs. So instead of resembling a giant crocodile, scientists understood that dinosaurs must have stood up, balancing on their hind limbs.

The Philadelphia naturalist and polymath Joseph Leidy, who named the *Hadrosaurus*, noted that, "this great herbivorous Lizard sustained itself in a semi-erect position… while it browsed on plants." To Leidy, *Hadrosaurus* was less a reptilian rhino and more like a kangaroo. The image of the dinosaur became that of an active creature who stood upright instead of slithering on the ground. The skeleton of the *Hadrosaurus* helped to create a more up-to-date model of the dinosaurs. The English artist and sculptor Benjamin Waterhouse Hawkins constructed a version for Philadelphia's Academy of Natural Sciences that stood about 30 feet in length.

Just as the *Hadrosaurus* helped establish a dinosaur posture different from what naturalists had previously suspected, another little-known species helped scientists determine whether dinosaurs were warm- or cold-blooded. The 19th-century comparison of dinosaurs to iguanas and crocodiles led naturalists to assume that they were cold-blooded creatures. However, in the late 19th century, the discovery of an agile raptor, *Laelaps aquilunguis*, later renamed the *Dryptosaurus*, revealed a dinosaur that was a ripping, tearing predator who moved about swiftly on two legs. The agility of this carnivore strengthened the argument for warm-blooded dinosaurs. It also planted the idea that not all dinosaurs went extinct, and that some may have evolved into birds.

The discovery of another fossil—a whole century later—sparked the idea that dinosaurs were related to birds. The 11-foot long, switchblade-clawed *Deinonychus antirrhopus*, named in 1969, was pieced together from the bones of multiple individuals found in a Montana quarry, along with a beaked herbivore that seemed to have been slaughtered. Based on their being found together, Yale paleontologist John Ostrom speculated that *Deinonychus* was a pack hunter that slashed at victims with swift motions of a frightening foot claw. Disemboweling looked to be his preferred mode of dispatch. In his description of *Deinonychus*, Ostrom emphasized the animal's fierceness. "When all these features are considered together," Ostrom wrote, "we have a rather convincing picture, I think, of *Deinonychus* as an active and very agile predator." There was little doubt at that point that the dinosaur's rate of metabolism was high. And as Ostrom continued his investigations, he realized that the formidable *Deinonychus* resembled a larger version of another animal—the first bird, *Archaeopteryx*. Dinosaurs, Ostrom proposed, did not go totally extinct. If birds evolved from dinosaurs like *Deinonychus*, then dinosaurs survived.

The discovery of *Deinonychus* helped spur the "Dinosaur Renaissance" of the 1970s and '80s. Dinosaurs suddenly became a subject of respectable scientific interest again and the new facts trickled back to revise the public's image of the celebrity creatures. In Steven Spielberg's 1993 blockbuster *Jurassic Park*, famous dinosaurs vividly flaunt their newly acquired characteristics. The *Brachiosaurus* stopped sunning itself in the Jurassic mornings to warm up and became a proud herbivore that strutted over floodplains to show off its elegant neck. *Tyrannosaurus* became a super-charged predator that terrified audiences. Large, hulking reptiles were replaced by active, bird-like animals that were far more complex than believed earlier.

Part of the complexity lay in dinosaurs' family structure. Before the Dinosaur Renaissance, researchers believed that dinosaur parents provided almost no care at all to their offspring. Another fossil find in 1979 in Montana challenged that narrative, spurring paleontologists Jack Horner and Robert Makela to discover entire nesting grounds where there were bones of adults as well as hatchlings. They concluded that at least one parent must have been looking after the babies and bringing food for them to eat and that the young were staying within the nest for some time after hatching. Researchers could no longer just assume that dinosaurs laid eggs and walked away from them. This dinosaur, dubbed *Maiasaura*, was an argument in favor of more intriguing—and caring—animals than had ever been suspected. Horner and Makela named her the "caring mother lizard," and it raised the possibility that other species, like *Stegosaurus* and *Triceratops*, partook in prolonged parental care.

But the latest, and greatest, alteration to our understanding of what dinosaurs were like came from a critter much smaller than either *Deinonychus* or *Maiasaura*. A theropod dinosaur, a distant and smaller cousin of *T. rex* and *Deinonychus, Sinosauropteryx* stood barely a foot off the ground. What made this creature fascinating was what covered its tiny frame. Instead of scales, its coat was a mane of filamentous feathers running along its back.

When paleontologists Philip Currie and Chen Peiji showed off a snapshot of *Sinosauropteryx* at a meeting in 1996 of the Society of Vertebrate Paleontology, their colleagues were astounded. Yale's Ostrom, who had long argued for bird-like dinosaurs on the basis of his own *Deinonychus* find as well as other discoveries, told *The New York Times* that the photo put him "in a state of shock." At long last, the crucial soft tissue connection between dinosaurs and birds had been discovered. To bastardize an Emily Dickinson quote, researchers had found that dinosaurs are the things with feathers.

The *Sinosauropteryx* was just the first of dozens of feathery fossils to be found in China. Together, these dinosaurs confirm that birds truly are dinosaurs, and that feathers were a feature shared among many dinosaur lineages. The 2012 announcement of a 30-foot-long *Tyrannosaur* covered in fuzz, named *Yutyrannus*, has even raised the distinct possibility that our cherished *T. rex* bore a fuzzy coat. This would mean a heady revision of how dinosaurs looked and what end they may have met.

Imagine the next *Jurassic Park* with an angry *T. rex* covered in feathers lunging at the tiny terrified humans. How we see dinosaurs will keep changing for as long as we study them, and lesser-known species will undoubtedly be at the heart of whatever major transmutations to dinosaur imagery come next.

Just how drastically our favorite dinosaurs will be changed by unsung species is an open-ended question. We haven't even found most dinosaurs yet. One 2006 estimate proposed that there may have been about 1,850 different types during their Triassic to Cretaceous heyday—a run from about 245 to 66 million years ago. If that's so, then the 500 or so genera named so far mark the start of our paleontological discoveries and might mean more changes for famous and beloved icons such as the *T. rex*. Dinosaurs are anything but set in stone.

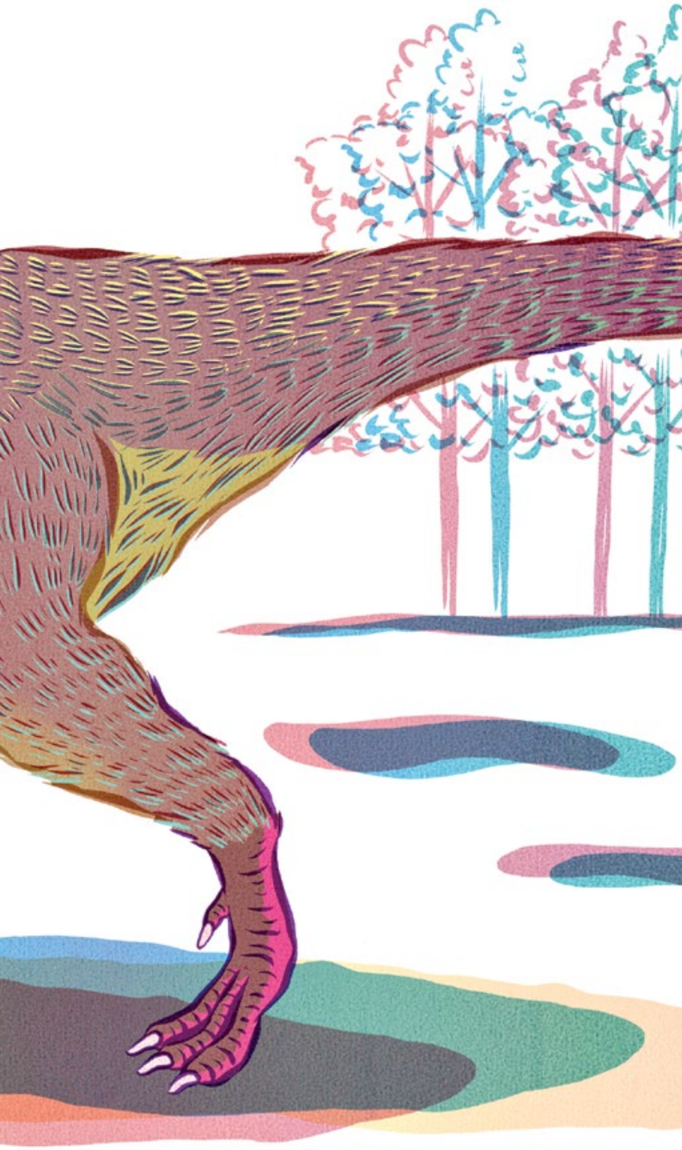
BRIAN SWITEK dressed up as a *Stegosaurus* when he was 5. He is the author of *My Beloved Brontosaurus*.

TYRANNOSAURUS REX was discovered in 1902 and quickly became the favorite flesh-tearing monster of sandboxes and science museum exhibits. Since it was unearthed as an incomplete skeleton, paleontologists filled in the details of his features based on how they thought all dinosaurs looked then. As scientific discoveries revealed more about dinosaur morphology, the King of Lizards' image was periodically updated. Here are the scientific findings that transformed the all-time most popular dinosaur from a slithering reptile to a dynamic predator. –*Yvonne Bang*

AERODYNAMIC (1969): Early on, *T. rex* was pictured as standing upright with its tail dragging. In 1969, while working on assembling a model for the British Museum, paleontologist Barney H. Newman argued that the vertebrae of its spinal column had to have been rigidly connected by tissue, preventing an upright bipedal dinosaur from bending down to feed nearer the ground. He reimagined *T. rex* as forward leaning, locomoting with knees high like an ostrich and its tail suspended in the air, acting as a counterweight. *T. Rex* looked ready to take flight.

BIRDS OF A FEATHER (1970s): *T. rex* has always been seen as a sharp-toothed predator, but its lizard ancestry gave it a reputation for being less than spry. The discovery of a new vicious dinosaur, *Deinonychus*, by Yale paleontologist John Ostrom in 1964, reinvented *T. rex*. *Deinonychus* had scythe-like claws that quickly dispatched its victims and seemed to share many bones with the "original bird," *Archaeopteryx*. So Ostrom championed the theory throughout the 1970s that birds and dinosaurs are of the same "theropod" family. Our lizard-like *T. rex* was remade into a limber and well-equipped hunter.

ILLUSTRATION BY JUNGYEON ROH



FOSSILIZED FEATHERS (1996): The imprint of *Sinosauropteryx*—a meat-eating dinosaur, measuring two feet from skull to tail tip—and its feathery coat were found in China, fortuitously preserved in volcanic ash. Another feathered dinosaur found in 2004, this time in T. *rex's* tyrannosauridae family, added momentum to the tantalizing idea that *T. rex* might too have been feathered. Feathers do not weather the test of time well: They are preserved only in certain rare conditions like fine clay and still water.

NOSE JOB (2001): In 2001, paleontologist and professor of anatomy Lawrence Witmer proposed that we rethink the facial structure of *T. rex*. In particular he said that its nose should be situated lower. Using 3D X-rays of nasal openings on the skulls of birds, crocodiles, and lizards, Witmer theorized that *T. rex* looked more like a terrestrial beast than a sea creature with a blowhole.

AN 8-TON TEENAGER (2001): Scientists had assumed that dinosaurs lived for more than 100 years, but discoveries in the 1990s showed that they died young. Dinosaur bones have annual rings, like trees. Biologist Gregory Erickson used these to deduce that various species of dinosaurs had a growth spurt in their teens, and died in their late 20s (if they weren't killed earlier). The oldest found *Rex*, Sue, was 28 years of age at death.

SHARP SENSE (2009): Biologist Thomas Holtz says that even for meat eaters, *Rex* had an acute sense of smell and keen eyesight, helping them remain at the top of the food chain. CT scans of *T. rex's* brain cavities revealed room for very large olfactory bulbs.

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Like

The Hannah Montana Hypothesis

Does the Fame Virus plague our youth, and is multimedia to blame?

BY JESSICA SEIGEL
ILLUSTRATIONS BY TOMASZ WALENTA

IT'S PAMPER TIME FOR Maddie, 16, who's sitting down for a manicure right now, but not before telling her 2,000 Twitter followers. "Spa day," the teen taps out, her long blonde hair clipped up in a sloppy bun as she streams updates throughout the day. "I love when my nails are freshly painted," she alerts soon after, presumably when the polish is dry. (Color: charcoal grey.)

The bubbly varsity team swimmer is a mini-celeb in her circle, with 1,200 Facebook friends and arguably more Twitter followers than anyone at her diverse suburban high school of 2,000 just west of Boston. And complete strangers around the world see her tweets, too, signing on to her feed after heartthrob Niall Horan, of the boy band One Direction, began following her. Yes, He of the spike-gelled mop-top.

"He has 15 million followers and only follows a couple thousand," says Maddie, who doesn't at all mind telling the story of how that happened (more on that later). "People are like, 'that's crazy.'" In another tweet, Maddie wonders why Miley Cyrus, her one-time role model and the ex-star of Disney's *Hannah Montana* sitcom, has gone punked out and potty-mouthed. "Miley, baby, what happened?" That information may seem like a trashy tabloid tidbit, but the theory about what's ailing today's youth centers on the popular TV show. Call it the Hannah Montana Hypothesis.

Researchers are warning that today's young are more obsessed with becoming famous than ever before, and rank fame as the most important thing in life. These psychologists believe that narcissism has been increasing from one generation to the next, with today's youth reaching a new level of vanity and idle dreams of grandeur. With 24/7 retweeting, liking, and following, every teen has a world audience to act out fantasies of becoming just like the stars they idolize. Stars might even follow them.

Maddie seems like a poster child for the social media-induced narcissism era as she broadcasts all day long about her hair, skin, school, friends, swimming, and fave celebs. The caption under her Instagram "selfie" photo, taken by pointing her iPhone down her legs in mid-pedicure, seems to say it all: "The Princess Life." "I post for the likes," she explains. "I post all the time." But her generation's princess—and prince—problem may be far more controversial than it seems.

AFTER A QUICK LOOK, the scientific evidence is clear. "Popular TV shows teach children fame is the most important value," stated the University of California, Los Angeles (UCLA) press announcement of the study by psychology professor Patricia Greenfield and her Ph.D. student, Yalda Uhls. Titled "The Rise of Fame: An Historical Content Analysis," the study evaluated the two most popular tween TV shows of every decade for the last 50 years. Recruited online, 60 reviewers rated the programs based on 16 moral values incorporating

Researchers are warning that today's young are more obsessed with becoming famous than ever before, and rank fame as the most important thing in life.

traits from cutting-edge research investigating what makes people desire fame. They ranked community feeling and benevolence as the most important moral concepts in *Andy Griffith* and *The Lucy Show*, which aired in 1967; *Laverne & Shirley* and *Happy Days*, which aired in 1977; *Growing Pains* and *Alf*, which aired in 1987; and *Sabrina the Teenage Witch* and *Boy Meets World*, which aired in 1997. In those decades, fame and achievement hovered at the bottom of the list. But in 2007, the moral values flipped—fame and achievement skyrocketed in *American Idol* (the talent competition) and *Hannah Montana*, in which high school student Miley Stewart (played by Miley Cyrus) leads a double life as a pop star. At the same time, community feeling and benevolence plummeted.

"The rise of fame in preteen television may be one influence in the documented rise of narcissism in our culture," Greenfield said in that press release, echoing the battle cry of a much-quoted group of psychologists claiming that today's youth are more selfish, vain, and conceited than past generations. "At an age when children are craving popularity, they're craving fame, but without understanding it should be tied to hard work or skill," says Uhls, a former film executive and a regional director of Common Sense Media, a non-profit advocacy group promoting educational programming and policy for kids. The results? Deflation. Disappointment. Slacking off. "Some kids could drop out of school because they see it as so easy," Uhls said in a follow-up telephone interview. National media including *USA Today*, CNN, and *Time* covered the study with little skepticism, pinning the blame on multimedia for saturating tweens with fame-hyping messages.

But it's not so clear cut. It turns out that neither the researchers nor their reviewers actually watched the programs in their study. Instead, the 60 participants evaluated summaries of the shows written by anonymous contributors to tv.com. That methodology is just one of many deep flaws in the research, according to Klaus Krippendorff, communications professor at the Annenberg School for Communication at the University of Pennsylvania, who wrote the textbook *Content Analysis*, now in its third edition.

"I wouldn't touch these conclusions with a ten foot pole," Krippendorff said. A sampling size of just two TV programs every decade is "ridiculously small," if not completely arbitrary, he pointed out, emphasizing the importance of representative samplings. "I would not generalize from this data to say there is a trend over time."

A content analysis, he explained, must evaluate content. Like film, television involves visuals, sound, and tone, such as jokes or sarcasm that communicate

"I wouldn't touch these conclusions with a ten foot pole," Krippendorff said.

implicit versus explicit meanings. In traditional methods, a small group of raters is trained, then tested on reliability and consistency in analyzing content—a labor-intensive process. So at best, Krippendorff concluded, this study could be seen as a survey of perceptions of past and current TV shows.

Uhls and Greenfield responded to the criticism by explaining that using untrained reviewers was, in fact, their research innovation. "The goal was not 'accurate coding,' but learning what impression each series was making on its audience," they wrote in an email. "In sum, the point was not to assess 'actual' content, but 'perceived' content." Yet their paper, sub-titled "A Content Analysis," only mentions audience perception in passing and repeatedly expounds on TV show values, as do the study's abstract and implications sections, the UCLA press release, and their comments to reporters.

If anything, the findings reveal what grown-ups think of children's TV, since the average rater was 39 years old, with only seven participants under 25. Adult disapproval, in fact, is why Uhls began her research—after noticing that when her daughter was 9 years old, her favorite shows seemed to involve an unusual number of fame-focused settings, ranging from *Hannah Montana* to Nickolodeon's *iCarly* (2007-2012), which was about a fictional teenage web mogul. In fact, the digital revolution is producing actual teen web moguls, like Summly founder Nick D'Aloisio, who was profiled in *Forbes* magazine after his company merged with Yahoo!. Then there is Daniil Kulchenko, who sold his first start-up at age 15 to cloud-computing company ActiveState for an undisclosed sum. But that doesn't seem to have entered into the UCLA researchers' equation.

When researchers like Krippendorff tackle content analysis, they typically use trained raters. But that would involve many hours of actual TV watching—and substantial resources. Luckily, Maddie has already logged many hours of actual TV watching and is available—when not working part-time at University Pizza.

"I LOVE *Hannah Montana*," Maddie says, excited by the idea of giving her own content analysis. She even singled out the tone, technically known as the implicit message. "It's lighthearted and funny and some people say the acting is really bad, but I think it's goofy and stupid in a funny way," she said. One of the funniest, goofiest things is that rock star Billy Ray Cyrus plays the fictional dad of Miley Stewart (Miley Cyrus) in *Hannah Montana*—and he's also her dad in real life. "You laugh at, like, that he's trying to act and stuff," Maddie explained. "But actually, he really can't act very well!" To young people, the interplay between the real and fictional set-up is hilarious.

The show, she explained, doesn't promote fame at all—but the opposite. "It related Hannah Montana the celebrity to being a real teenager," Maddie continued, citing the movie version when Hannah Montana

finally reveals her identity as a secret star who's really just a normal teenager. Maddie says the message brings down to earth the celebrities that she already adores and sees promoted everywhere, especially in magazines. "The show was really based on friendship—keeping your friends and family really close," Maddie says. "When you watch it, you appreciate your family and friends even more."

FEARS ABOUT THE CULT of celebrity run amok aren't new. Historian and social critic Christopher Lasch wrote about it in his 1979 bestseller, *The Culture of Narcissism: American Life in An Age of Diminishing Expectations.* Back then, a new global media—TV—was being blamed for spreading fast fame in the days when only three major TV networks existed. Today, with access to thousands of TV channels, millions of YouTube videos, and 1.73 billion social media users, the debate is more heated than ever: Does easier access to fame spread narcissism like germs—especially to the young—or simply enable pre-existing narcissists to draw more attention?

A few years ago, S. Mark Young, a communications and business professor at the University of Southern California, Los Angeles, and Drew Pinsky, doctor and TV personality, teamed up to tackle the question. They used the Narcissistic Personality Inventory (NPI)—a 40-point questionnaire developed by two University of California, Berkeley professors to assess traits attributed to narcissism such as exhibitionism, exploitativeness, superiority, and vanity—to measure 200 celebrities from Pinsky's radio show, *LoveLine*. Reality TV stars scored highest, followed by comedians, actors, and musicians, in that order—all clocking in higher than the average person.

Young and Pinsky found that the length of years in the limelight did not correlate with score. They theorized that being famous does not cause narcissism, but rather attracts it. (Otherwise, the longer a person spent in the limelight, the higher she'd score.) Reality TV, they concluded, lets people with "limited abilities believe that they can succeed in the entertainment industry." The study's point is not that individuals with narrow thespian skills like Kim Kardashian and Honey Boo Boo do succeed, but rather that selfish, self-aggrandizing, vain people, aka narcissists, are over-represented on TV and social media—because they love drama, perform well in public, and obsessively groom their image.

Such personalities have been dubbed "superspreaders" and are said to transmit narcissism like a virus. That is the theory of the academic camp led by Jean Twenge, psychology professor at San Diego State University and co-author of *Generation Me: Why*

Today's Young Americans Are More Confident, Assertive, Entitled—and More Miserable Than Ever Before and *The Narcissism Epidemic: Living in the Age of Entitlement*.

Twenge and co-author Keith Campbell compare celebrities to Typhoid Marys who infect the masses with the sickness of vainglory just like the notorious 1900s cook. But they don't detail how celebs poison others with narcissism, except through a generalized copycat principle—see it, wannabe it—a theory Lasch also supported.

On the contrary, they theorize that today's youth are the most infected of all age groups with mimetic dreams of tinsel laurels because they're malleable "like clay." As evidence, Twenge and Campbell point to a rise in college students' NPI scores in the last 20 years—although Twenge concedes that no good longitudinal research on adult NPI scores exists as a comparison. To draw conclusions over time, a comparison control group is required, but none exists. Thousands of college students take the NPI in basic psychology courses, but no adults do. Yet, Twenge believes her team overcame that obstacle. "We were able to find enough data to say the pieces of the puzzle come together," she says. And with the puzzle supposedly assembled, Twenge and her camp seem to have gained the cultural upper hand on the popular view that today's youth are spoiled trophy-grabbers, with celebrity culture, social media, lax parenting, and the self-esteem movement to blame.

BUT A COUNTER MOVEMENT of psychology researchers is on the march—at least in academic journals. Spearheaded by Kali Trzesniewski at the University of California, Davis and M. Brent Donnellan at Michigan State University, the skeptics have responded with a flurry of detailed critiques of Twenge and company's data, calculations, conclusions, and the NPI index itself. First, they argue that the uptick in college NPI scores comes down to one to two points out of 40, barely reaching statistical significance. "I don't question that norms of behavior have changed," says Trzesniewski. "But when you get to core [personality] traits, there just doesn't seem to be a difference."

The second problem is the NPI's questionnaire, the skeptics say. Question 33, for example, offers the choice between "I would prefer to be a leader" and "It makes little difference to me whether I am a leader or not." Question 8 offers the options "I will be a success" or "I am not too concerned about success." In both cases, choosing the first option raises the NPI score one point. "The NPI is an odd and very *American* set of items," Wellesley College psychology professor Jonathan Cheek, who studies the intellectual history of narcissism, wrote in an email. "Twenge used a bad scale—was misled in a way, but avoided looking for subtleties and complexities in this complex psychological construct."

Looking to the real world for evidence, the skeptics cite falling rates of youth alcoholism, crime, car accidents, pregnancy, and childbirth to argue that today's

"Ridicule of the young is in many ways the last respectable prejudice," Arnett says.

generation is not more risk-taking, impulsive, or aggressive—all narcissism hallmarks—but less. "This is not merely an academic argument," says Jeffrey Jensen Arnett, psychology professor at Clark University who coined the term "emerging adulthood" for today's unsettled 20-somethings. "These stereotypes are destructive to young people," he says. "Ridicule of the young is in many ways the last respectable prejudice."

ADD RIDICULE OF HANNAH Montana to the list. Briefed on the controversy over her generation, Maddie scoffed at the notion that adoring the Disney sitcom and a celebrity Twitter follower make her narcissistic. While it might seem biased to ask her to evaluate herself, the NPI scores are self-rated. So here's hers: "I don't mind not being famous. I wouldn't want to give up my sense of privacy," says Maddie, the daughter of a graduate school administrative assistant/tap dance instructor and wine and spirit sales director. "Celebrities get expensive things and expensive tastes and they're not as appreciative of the things they have."

She tells how much she appreciates her parents and friends, just like her Instagram tribute to her best buddy since 6th grade, Hayley: "I am so lucky to be able to go to you with anything. You're the sweetest person ever and so pretty! You're also weird, but that's alright, but happy sixteenth."

But what about her self-absorbed Twitter feed? "I'm a high school kid," she responds. "I tweet about things teenagers think about, like our feelings—and food." High school stress. Books, too. And teen crushes. That brings us to one early morning at 5:30, when Maddie and three BFFs ventured to the mall to meet One Direction, only to find about a hundred girls with sleeping bags already in line. Somehow, Maddie managed to pass a card to the band's manager for Niall, confessing her devotion and asking the 19-year-old Irish singer to follow her on Twitter. Months later, he did.

Despite her brush with fame, Maddie likes sciences and ponders a future in photography, not showbiz. She is also developing her own theories about how social media affects people, and she worries about it, too. "I know little kids who have Instagrams and Twitter and stuff, and they're like 8 years old," she says of the girls she babysits. "The generation below us—all the technology is making them grow up quicker. Some parents have no idea. That's the scary part."

JESSICA SEIGEL is an award-winning journalist, New York University adjunct journalism professor, and former *Chicago Tribune* national correspondent. Her work has appeared in *The New York Times*, *National Public Radio*, *Salon*, and other publications.

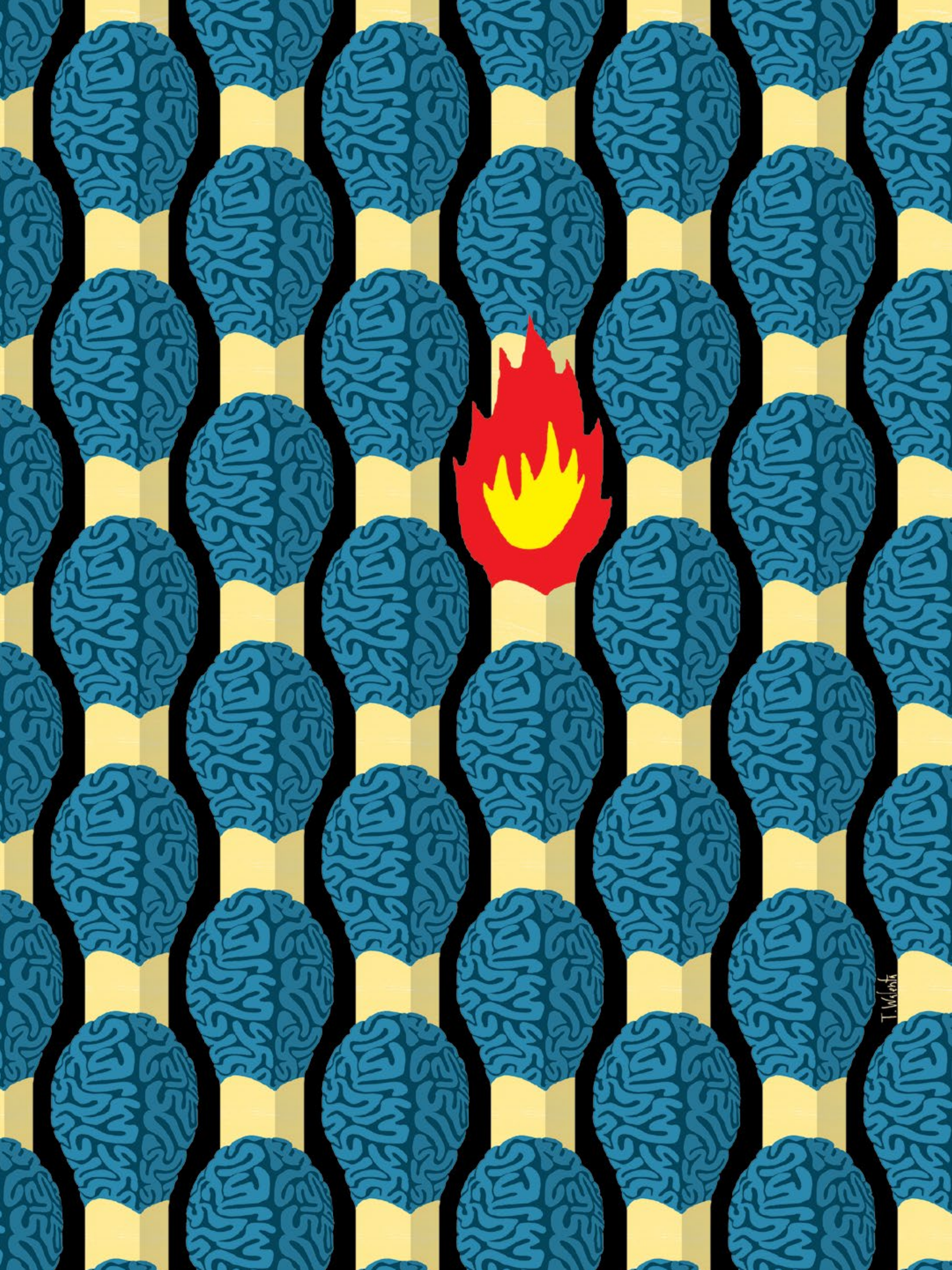
The Meme as Meme

Why do things go viral, and should we care?

BY ABBY RABINOWITZ

O**N APRIL 11,** 2012, Zeddie Little appeared on *Good Morning America*, wearing the radiant, slightly perplexed smile of one enjoying instant fame. About a week earlier, Little had been a normal, if handsome, 25-year-old trying to make it in public relations. Then on March 31, he was photographed amid a crowd of runners in a South Carolina race by a stranger, Will King, who posted the image to a social networking website, Reddit. Dubbed "Ridiculously Photogenic Guy," Little's picture circulated on Facebook, Twitter, and Tumblr, accruing likes, comments, and captions ("Picture gets put up as employee of the month/for a company he doesn't work for"). It spawned spinoffs (Ridiculously Photogenic Dog, Prisoner, and Syrian Rebel) and leapt to the mainstream media. At a high point, *ABC Morning News* reported that a Google search for "Zeddie Little" yielded 59 million hits.

ILLUSTRATIONS BY TOMASZ WALENTA


T. Walenta

Why the sudden fame? The truth is that Little hadn't become famous: His meme had. According to website Know Your Meme, which documents viral Internet phenomena, a meme is "a piece of content or an idea that's passed from person to person, changing and evolving along the way." Ridiculously Photogenic Guy is a kind of Internet meme represented by LOL cats: that is, a photograph, video, or cartoon, often overlaid with a snarky message, perfect for incubating in the bored, fertile minds of cubicle workers and college students. In an age where politicians campaign through social media and viral marketers ponder the appeal of sneezing baby pandas, memes are more important than ever—however trivial they may seem.

But trawling the Internet, I found a strange paradox. While memes were everywhere, serious meme theory was almost nowhere. Richard Dawkins, the famous evolutionary biologist who coined the word "meme" in his classic 1976 book, *The Selfish Gene*, seemed bent on disowning the Internet variety, calling it a "hijacking" of the original term. The peer-reviewed *Journal of Memetics* folded in 2005. "The term has moved away from its theoretical beginnings, and a lot of people don't know or care about its theoretical use," philosopher and meme theorist Daniel Dennett told me. What has happened to the idea of the meme, and what does that evolution reveal about its usefulness as a concept?

Memes were originally framed in relationship to genes. In *The Selfish Gene*, Dawkins claimed that humans are "survival machines" for our genes, the replicating molecules that emerged from the primordial soup and that, through mutation and natural selection, evolved to generate beings that were more effective as carriers and propagators of genes. Still, Dawkins explained, genes could not account for all of human behavior, particularly the evolution of cultures. So he identified a second replicator, a "unit of cultural transmission" that he believed was "leaping from brain to brain" through imitation. He named these units "memes," an adaption of the Greek word *mimene*, "to imitate."

Dawkins' memes include everything from ideas, songs, and religious ideals to pottery fads. Like genes, memes mutate and evolve, competing for a limited resource—namely, our attention. Memes are, in Dawkins' view, viruses of the mind—infectious. The successful ones grow exponentially, like a super flu. While memes are sometimes malignant (hellfire and faith, for atheist Dawkins), sometimes benign (catchy songs), and sometimes terrible for our genes (abstinence), memes do not have conscious motives. But still, he claims, memes parasitize us and drive us.

Pinpointing when memes first made the leap to the Internet is tricky. Nowadays, we might think of the dancing baby, also known as Baby Cha-Cha, that grooved into our inboxes in the 1990s. It was a kind of proto-meme, but no one called it that at the time. The first reference I could find to an "Internet meme" appeared in a footnote in a 2003 academic article, describing an important event in the life of Jonah Peretti, co-founder of the hugely successful websites The Huffington Post and BuzzFeed. In 2001, as a procrastinating graduate student at MIT, Peretti decided to order a pair of Nike sneakers customized to read "sweatshop." Nike refused. Peretti forwarded the email exchange to friends, who sent it on and on, until the story leapt to the mainstream media, where Peretti debated a Nike representative on NBC's *Today Show*. Peretti later wrote, "Without really trying, I had released what biologist Richard Dawkins calls a meme."

Peretti concluded that the email chain had spread exponentially "because it had access to such a wide range of different social networks." Like Dawkins, he saw that a meme's success depends on other memes, its ecosystem—and further saw that Internet memes' ecosystems were online social networks, years before Facebook existed. According to a recent profile in *New York Magazine*, the Nike experience was formative for Peretti, who created BuzzFeed with the explicit goal of creating viral Internet memes. The company uses a formula called "Big Seed Marketing," which begins with an equation describing the growth of a virus, the spread of a disease.

From the perspective of serious meme theorists, Internet memes have trivialized and distorted the spirit of the idea. Dennett told me that, in a planned workshop to be held in May 2014, he hopes to "rehabilitate the term in a very precise kind of way" for studying cultural evolution.

According to Dawkins, what sets Internet memes apart is how they are created. "Instead of mutating by random chance before spreading by a form of

Darwinian selection, Internet memes are altered deliberately by human creativity," he explained in a recent video released by the advertising agency Saatchi & Saatchi. He seems to think that the fact that Internet memes are engineered to go viral, rather than evolving by way of natural selection, is a salient difference that distinguishes them from other memes—which is arguable, since what catches fire on the Internet can be as much a product of luck as any unexpected mutation.

But if the concept of memes can really offer new insight into the intricate web of digital culture and cultural evolution more broadly, why have academics neglected it? Looking for answers, I called Susan Blackmore, a British professor who may be one of the last defenders of memetics as a scientific field. In a 2008 TED talk, Blackmore is an animated speaker, bright-eyed and wiry, her short grey hair dyed with streaks of blue. I reached her at her home in Devon, England, where she is occasionally joined in the garden by Dawkins and Dennett for meetings of the "meme lab." "It's only a bit of fun, nothing serious," Blackmore said. Sometimes, members try experiments, like folding Chinese sailing ships from origami, itself a kind of meme. She remembered a March meeting in which the issue of Internet memes arose, saying, "Richard was upset because he invented the term, which shouldn't just be about viral Internet memes. It's a very powerful concept for understanding why humans are the way we are."

For Blackmore, memetics is a science. An Oxford-educated psychologist, her early work was on telepathy, which she spent years investigating after an out-of-body experience at the age of 19. She subsequently found no evidence for the existence of paranormal phenomena, but she was no stranger to pushing scientific frontiers. It is perhaps unsurprising that she decided to flesh out memetics. Dawkins wrote that, with memes, he did not intend to "sculpt a grand theory of human culture." In her 1999 book, *The Meme Machine*, Blackmore does just that. She argues that everything from the development of language to our big brains were products of "memetic drive." This is perhaps her most radical claim: that memes make us do things.

Considering this idea in his book *Consciousness Explained*, Dennett writes, "I don't know about you, but I'm not initially attracted by the idea of my brain as a sort of dung heap in which the larvae of other peoples' ideas renew themselves… who's in charge, according to this vision—we or our memes?" Still, Dennett, too, became a major proponent of meme theory. Speaking on the phone, he used memes to explain the joy we take in our culture and related decisions not to procreate wildly. College, he pointed out, is a great underminer of genetic fitness. Reading Blackmore and Dennett, the idea of meme as mental parasite becomes both more and less convincing: If we are created and driven by our memes, then we *are* our memes, a duality that Dennett himself seems to recognize.

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Yet, the very breadth of the concept makes it difficult to approach memes from the perspective of serious, evidence-based science. In the analogy to genes, memes have inevitably disappointed. As Dawkins himself wrote, memes, as entities, are more vague than genes, where alleles compete to hold the same "chromosomal slots." Unlike genes, memes are not directly observable and have high rates of mutation. Also, no one seems to be sure if memes exist. On the phone, Blackmore told me "the one good reason" memetics might not be a science: "There has been no example of where some scientific discovery has been made using meme theory, that couldn't have been made any other way." Still, Blackmore told me that people are doing research on memes—they just don't call them by that name.

Looking for meme theory at work, I found network theory, an interdisciplinary field that unites computer science, statistics, physics, ecology, and even marketing. "If you want to use memetics to explain

'everything,' like how religion spreads, the problem is the data," said Michele Coscia, a researcher at the Harvard Kennedy School who recently wrote a paper displaying a statistical "decision tree" that described the success of memes like Ridiculously Photogenic Guy. For Coscia, Internet memes, with their visible mutations and view counts, solved the problem of empirical evidence, allowing him to do work he sees as analogous to genetics experiments.

Perhaps the notion of the meme is evolving in the direction of its own survival. The term "Internet meme" appears to be growing exponentially from year to year, in classical memetic fashion. This is what Bob Scott, a digital humanities librarian at Columbia University, found when he ran various searches on the comprehensive news and wire-service aggregator LexisNexis. He saw that the term "Internet meme" showed up with the new millennium and really took off in 2004, with references roughly doubling each year thereafter.

Infectious Internet memes are now big business. BuzzFeed now draws 85 million unique visitors a month, compared to *The New York Times*' website at 29 million, and was recently valued at $200 million. Its staff trawl the Internet for viral content and curate it, adding news stories, humor pieces, and advertisements, or "sponsored posts." These categories can be hard to disentangle, even though ads are printed on a taupe background. Scrolling through BuzzFeed, I read: "20 People We Hope to Never See Promoted on OK Cupid," (which was an ad by Virgin Mobile), a new story on poisoned Indian children, and a post about a Republican congressman who had "live tweeted" Jay-Z's new album. It turned out that "23 Times When Wal-Mart Didn't Disappoint" was not an ad, but still, the post made me think about how subversive humor—the kind that made Peretti's email exchange with Nike so popular—could be used to advertise one of America's least-subversive mega-chains.

While entertaining bored office workers seems harmless enough, there is something troubling about a

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multi-million dollar company using our minds as petri dishes in which to grow its ideas. I began to wonder if Dawkins was right—if the term meme is really being hijacked, rather than mindlessly evolving like bacteria. The idea of memes "forces you to recognize that we humans are not entirely the center of the universe where information is concerned—we're vehicles and not necessarily in charge," said James Gleick, author of *The Information: A History, A Theory, A Flood*, when I spoke to him on the phone. "It's a humbling thing."

It is more humbling still to think that our minds can be seduced not through the agency of memes, as Blackmore sees it, but through human agency and clever algorithms. Not by religions or quirks of culture, but by a never-ending list of stories that make us laugh. Even if the meme meme is too broad for empirical study, it offers us a powerful metaphor for how we absorb other peoples' ideas, and how they absorb us. So maybe this is what meme theory can ultimately give us: the insight we need to put LOL cats aside—and get down to work.

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Homo Narrativus and the Trouble with Fame

We think that fame is deserved. We are wrong

BY PETER SHERIDAN DODDS

O**UR UNDERSTANDING OF FAME** is critical to how we see each other and our society. But it is also badly wrong. Let me tell you why. We humans are storytelling and story-finding machines: *homo narrativus*, if you will. In making sense of the world, we look for the shapes of meaningful narratives in everything. Even in science, we enjoy mathematical equations and algorithms because they are a kind of universal story. For example, the oceans and atmosphere, the blood in your body, and honey are all fluids that flow according to a single, beautiful set of equations called the Navier-Stokes equations.

ILLUSTRATIONS BY DANIEL ZALKUS

Fame has much less to do with intrinsic quality than we believe it does.

In our everyday, human stories, far away from science, we have a limited (if generous) capacity to entertain randomness—we are certainly not *homo probabilisticus*. Too many coincidences in a movie or book will render it unbelievable and unpalatable. We would think to ourselves, "that would never happen in real life!" This skews our stories. We tend to find or create story threads where there are none. While it can sometimes be useful to err on the side of causality, the fact remains that our tendency toward teleological explanations often oversteps the evidence.

We also instinctively build our stories around individuals. To see evidence of this, we need only to look to local coverage of a recent disaster. For example, one article in *The New York Times* on Hurricane Sandy discussed the (unproven) fact that more babies are generated when generators fail. It opened with the line:

"Late last October, Hurricane Sandy pumped six feet of water into the lobby of a residential building in downtown Jersey City, trapping Meaghan B. Murphy and her husband, Patrick, in their apartment and leaving them without electricity for days."

Another *Times* article discussed the loss of life from the storm, starting with:

"In the days after Hurricane Sandy swept through the Rockaways, residents were left to sift through the devastation, taking stock of who and what had survived. But few seemed to notice Keith Lancaster was missing."

Both stories tether the complex, stochastic narrative of a larger population to that of an individual. We can't blame the *Times* here: This kind of narrative works. We can put ourselves into that person's mind, walk in their shoes, and travel in their story.

But social groups are far more complicated than any individual story. Networked, distributed, conflicting, and changing, they do not simply map onto an individual. For this reason, it's unnatural and very difficult to put ourselves into the collective minds of groups. Even a group of two is too much—we have to side with one person or switch between points of view. We are embodied stories of one.

So, when we discuss groups, we are left without metaphor. What do we do as a result? We force our single-body stories onto them: Groups become one dominant person—a monarch, the President, Michael Jordan—plus a supporting cast.

These two traits—our compulsion to tell stories, and our bias towards the individual—conspire to ruin our intuitive understanding of fame. They cause us to believe that fame is earned, that it is the result of the intrinsic properties of the famous person or object. Consider, for example, the *Mona Lisa*, perhaps the most famous painting in the world. Its fame is ascribed to all manner of intrinsic qualities: the subject's mysterious smile, her changeable expression, the way her eyes follow you, da Vinci's novel use of *sfumato*, the individual genius of Leonardo himself.

This has the makings of an excellent story. It's simple and causal, and it means that the *Mona Lisa's* fame was inevitable, and deserved. But it's the wrong story. If we travel to the Louvre, we find ourselves initially bemused by the surprising smallness of the *Mona Lisa*—it's only 30 inches by 21 inches. We observe that museum-goers pause for a few minutes at most in front of the painting. And we wonder if this is really the best we could do. As Donald Sassoon lays out in his book *Becoming Mona Lisa*, Leonardo's now-great painting took 400 years to become world-renowned, and jumped in fame

only after being stolen and later vandalized—certainly not events dictated by some intrinsic quality.

My own research has shown that fame has much less to do with intrinsic quality than we believe it does, and much more to do with the characteristics of the people among whom fame spreads. For example, in 2006, Matt Salganik, myself, and Duncan Watts reported the results of an online experiment of ours called Music Lab.[1] We gathered roughly 14,000 online participants, and gave them a total of 48 songs by unknown artists to listen to, rate, and download. What we didn't tell them was that they were randomly assigned to nine separate worlds: one world in which participants acted independently of each other, and eight parallel social worlds in which participants saw the current number of downloads of each song within their world—an indication of popularity.

The independent world served as a control to the eight social worlds. The popularity of songs in this world reflected the intrinsic "quality" of the songs. There were a few songs that did poorly in this world, plus all eight social worlds, and others that performed reliably well.

Things were very different in the social worlds. Here, rankings were much more affected by chance and the choices made by early participants: One song, for example, ranked first in one world and 40th in another. What's more, we were able to influence the song rankings by tweaking the strength of the social "signal" in each world, through varying whether the songs were arranged randomly, in a jukebox layout, or in order of the number of previous downloads. The experiment showed clearly that people like to imitate each other. Even weak social signaling skewed the popularity distributions significantly.

As we upped the signaling strength, the inequality among songs increased. The famous became more famous. But the popularity ordering began to differ more strongly between worlds: The choices of the early participants mattered more, and the system became more uncertain.

The data implies that there is no such thing as fate, only the story of fate. This idea is encoded in the etymology of the word: "fate" derives from the Latin *fatus*, meaning "spoken"—talk that is done—in direct

There is no such thing as fate, only the story of fate.

opposition to the root of "fame," which is *fāma*, meaning "talk." Destiny is not deterministic but probabilistic: Re-run the world, and the outcomes may well change. In fact, social systems bear a sensitivity to initial conditions that is the hallmark of chaos theory.

But most importantly, the experiment highlights the role of imitation. The next time you listen to Justin Bieber, and wonder, "Why?" remember that global success has more to do with social imitation than anything else. We have an extraordinary ability and drive to replicate each other's physical actions and mental processes. Copying is a fundamental part of how we learn, it gives us social cohesion, and it signals group affiliation. It is so pervasive that small moments of mimicry can fall outside of our attention, allowing us to misattribute fame. The origin of global fame is primarily the ability of a given system to allow the faithful copying of a given message.

A useful analogy might be the match and the wildfire. Try this piece of pulp fiction I've made up:

When a matchbox full of lazily dreaming future grill-lighters was bought at a small-town store on a hot summer day in the California desert, little did it know that one of its passengers would become the most notorious, most sought after weapon of all time. Two weeks later one of its matches would be used to start a wildfire that would burn for months and destroy 50 million acres. Anyone armed with a match like this one would be able to take over the world.

This is a patently ridiculous story—a single match is not the entire reason for a wildfire starting and spreading. But that's exactly how we naturally think about social wildfires: that the match is the key. In fact, there are two requirements: a local requirement (a spark), and a global requirement (the ability of the fire to spread). And it's the second component that is actually the bottleneck: If a forest is dangerously dry, any spark can start a fire. Sparks are easy to come by, and are not intrinsically special.

Our research has shown that a match-centric viewpoint completely fails to describe many model social (and other) networks. There is nothing in a mathematical description of spreading fame (see The Language of Fame) about the match that sets the fire going—instead, it's all about how the network connects, and how acceptance of a message spreads along links between people. Just as real forests must be ready to burn before a forest fire can erupt, the key condition for spreading in social networks is a global one: Many average, trusting people need to be able to experience and then want to share choices in their social networks, far away from the source.

Network models of fame can provide counter-intuitive insights. For example, people with many friends can actually impede the growth of a social contagion, rather than accelerate it. To see how this might happen, let's look at a highly idealized social wildfire called threshold contagion, first explored in model form by the Nobelist Thomas Schelling in his work on racial segregation. Threshold behavior works like this: If enough of your friends believe in something, then so do you. This is called "social proof,"[2] and is a core kind of interpersonal influence mechanism at work in our Music Lab experiment.

Imagine a population where everyone will believe a specific message if at least 1 in 5 of their friends does. In the figure on the next page, people are represented by the letters *A* through *E*. Friendships are represented by arrows, and time is represented by the letter *t*. The message that has been earlier taken on by *A* starts to spread, first to *C* and *E* (who hear the message from 1 in 5 and 1 in 3 of their friends). Then *B* switches because they now hear the message from 2 in 8 friends. But *D* continues to resist as its signal remains at 1 in 6, a precarious position.

Unlike the spread of a biological disease, threshold contagion does not spread through well-connected nodes. In fact, these nodes tend to resist the message. Instead, the initial message spreads far if there are sufficiently many nodes that are both a little influential (they have a moderate number of friends) and a little susceptible to being influenced.

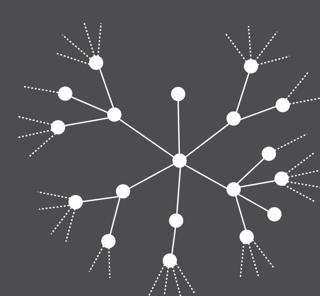
We also observe that small changes in the population's behavior or the structure of their social networks can lead to big differences globally. If everyone's threshold was 1 in 4 instead of 1 in 5 for this message, then

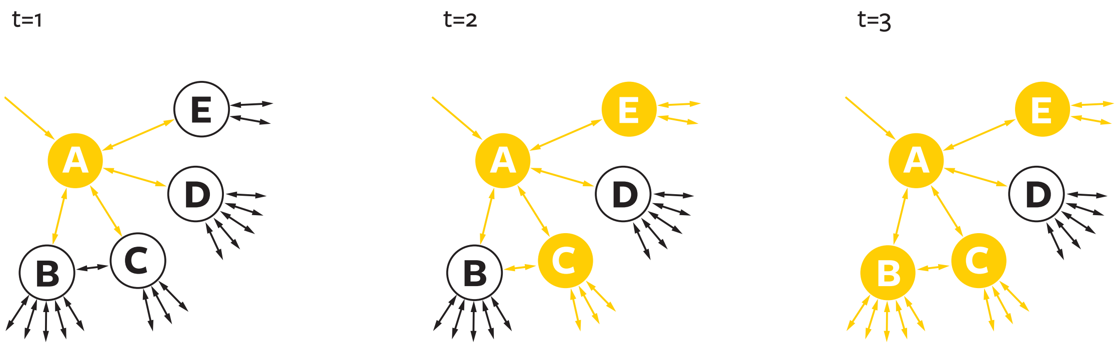
The Language of Fame

Let's represent people as nodes in a simple random network like the one pictured below. The sole defining feature of any node in a random network is the number of links it has, or its "degree," which we'll call k. Instead of thinking about infected nodes, it's more useful to think about the infected links that emanate from infected nodes. First, imagine we're traveling along a link in our network away from a node (infected or not). The probability that we reach a node with k friends can be written as $kP_k / \langle k \rangle$, where P_k is the probability that a randomly chosen node has degree k, and the normalization $\langle k \rangle$ is the average degree over the entire network. Now if a message is passing along this link, the receiving node will either reject the message or become infected and generate k-1 new infected links. Let's define β_k to be the probability that the receiving node is infected by the sending node's message. Then we can write the following expression for something we call the gain ratio, R,

$$R = \sum_{k=0}^{\infty} \frac{kP_k}{\langle k \rangle} \bullet (k - 1) \bullet \beta_k$$

which is the expected new number of infected links generated by a single infected link. If $R > 1$, infected links beget more infected links, and the message will successfully spread throughout the network.





individual *a* would not have repeated the message in the first place and spreading would have locally stopped there. If everyone's threshold was low, say 1 in 10, then the message would have spread immediately through this subnetwork in one time step, converting *d* as well.

For more complicated model networks, where our mathematical analyses comes up short, Duncan Watts and myself have studied social contagion and influence through simulation. In our paper, "Influentials, Networks, and Public Opinion Formation,"[3] we again found that, for certain networks, individuals with many friends were actually less useful for spreading social contagion, and were less able to start social wildfires than those with a moderate number. The research also showed that, for many kinds of complex networks, the power of the match to generate a social contagion is greatly limited. Taken together, the results put into question the existence of hyper-influentials or "opinion leaders"—those few, special, and above all, hypothetical people who are responsible for the choices of the rest of the population. The matches of society.

But the idea of the opinion leader persists. Why? Because we tell stories, and because we focus on individuals. We can't resist the promise that if we can find these special people, we can change society to our ends, whether it be to sell products or to improve people's health. Our plight is made worse by "survivorship bias"—the tendency to focus on successful stories of such influencers.

The cover of Malcolm Gladwell's massively successful book about social wildfire, *The Tipping Point*, shows an unused match above the words "How little things can make a big difference." But the forest is not in the frame, and it should be.

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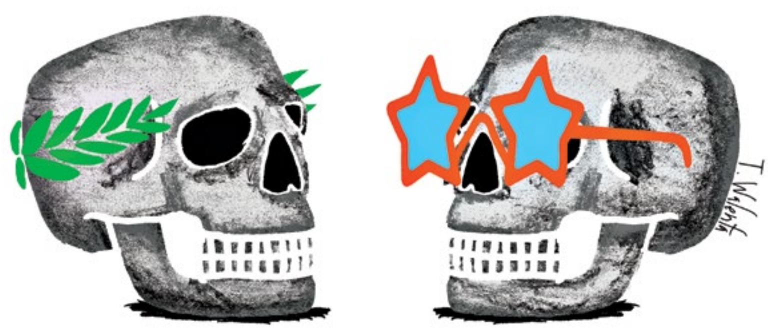
"EINSTEIN'S CODE" BY GRACIA LAM

Drop-Dead Famous

If we are to learn how to die, we need teachers

BY TOM PAYNE



DEATH IS A UNIVERSAL rite of passage, but, with a single exception, it always happens to someone else. In understanding death we need to turn our gaze to those around us. This was easy when death was a feature of daily life, as it has been for most of human history: on the street, the gallows, or, if at home, among the extended family. But nowadays, in the West, mortality has withdrawn to the private, sanitized space of the hospital ward, and has become all too easy to ignore. Or it would be, if the famous were not there to ensure death stayed squarely in the public eye.

ILLUSTRATIONS BY TOMASZ WALENTA

Mortality has withdrawn to the private, sanitized space of the hospital ward, and has become all too easy to ignore.

Celebrities have long offered lessons in how to die. "Those that the gods love, die young," is an idea dating back to Ancient Greece, linking passion and talent to a premature demise. Aristotle believed that the warmth of the heart sustained life, and death came when the heart cooled. It followed that a hotter flame, fanned by over-exercise or ardor, would burn out more quickly.

It followed, then, that glorious and poetic ends ought to await Greek heroes. Homer's *Iliad*, the ancient epic poem that depicts events from the Greek siege of Troy, describes the deaths of more than 250 characters in almost loving detail. A passage picked at random has Polypoetes, son of Peirithous, plunging a spear through the skull and into the brain of Damasus, shortly before Leonteus finishes Hippomachus with a blow to the groin. Note that we have the names, not only of the killer, but also of the fallen. They, too, have their memorial.

The *Iliad* taught readers that death, as much as life, was to be savored and celebrated, while the story's wealth of bloody vignettes seemed to point towards death's inevitability. In an era of limited medical knowledge, its graphic accounts of battle also served as a quasi-scientific anatomy primer. The passage in which Thoon, a Trojan, is killed when Antilochus slices "the vein that runs up the back and reaches the neck," helped ancient doctors determine the location of the vena cava.

As Plato and Xenophon have shown, Homer was a guide to life: A man wanting to learn how to steer a horse would refer to the relevant passage in the *Iliad*. So it was with death, which men in Greek city-states were expected to confront in any one of the endless conflicts among neighbors and former allies. The trainee hoplite might ask himself, "If I die, how bad can it be? If Thoon can manage it, so can I." Ordinary deaths might be prosaic and unwilled; those of warriors, by contrast, could be heroic and even beautiful.

Aside from death in battle, the Greeks prized vigorous, heart-cooking competition as a quick route to fame. A full suite of challenges was available, including all-in wrestling, the javelin, and horseback riding, all of which Galen discouraged as being "contra-natural" and injurious to health. Like the soldier, the athlete's daring put him in touch with another world, and so his passing—even if tormented or tragic—seemed like a natural progression on a journey already undertaken. The spectator, desirous to learn of death and courage, compelled the athlete to pay the ultimate price for fame.

The medium may have changed from Homer to Twitter and texting, but the message is the same.

But what lessons do the famous offer today, in the era of the eked-out, medicalized decline? A startling example is Jade Goody, a British star of reality television who died in 2009. She had become so famous on the show *Big Brother* in 2002 that she qualified, several years later, to be a resident in *Celebrity Big Brother*, where she drew outraged reactions to her bullying and racism, caught on the ever-present cameras. But the tenor of the public conversation about her changed after she received a diagnosis of advanced cervical cancer.

Goody appeared determined to make her death mean something. Her stage-managed decline achieved at least two things: The money from the media coverage enabled her young children to have the sort of start in life that she was denied, and it raised awareness of the need for regular cervical cancer tests. A study released in June 2013 revealed that, in the year that Goody was diagnosed and died of the illness, an extra 400,000 women attended cervical screening appointments. Like the anatomical death of a Homeric hero, Goody's death was a didactic and moving spectacle. She used its public character to claim for herself a kind of power, and a form of redemption, against the idea of death as a mere failure of the body, a running-out of heat.

Kate Granger has gone a step further. The manner of her dying has become the basis of her fame. At 31, the Yorkshire-based doctor is living with a diagnosis of terminal cancer. Far from denying her illness, she has come to respect it, writing about the experience in books, a blog, and to her nearly 15,000 Twitter followers. She hopes to use her fame to help dispel the fear and denial that surround death. "It would be really interesting to tweet how I am feeling at the end and how it is going," she said in a May 2013 article in *The Times UK*. "I think that people don't want to accept that dying comes to us all. There is this reluctance and inability to contemplate dying."

Now more than ever, we need famous deaths to make the end familiar. The medium may have changed from Homer to Twitter and texting, but the message is the same. Seamus Heaney, the great Irish poet, communicated his last words via text message: "*Noli timere*," he wrote to his wife, before he passed away on Aug. 30, 2013, at the age of 74. It is a Latin phrase, meaning "do not be afraid."

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T. Walenta

06

INFORMATION WARFARE IS ALL around us. With government spying scandals and attacks on financial and news websites, the past year has done nothing if not show the importance of making, breaking, and stealing secret codes. But humans are not unique in our dependence on codes. In fact, we're a few billion years late to the party.

In this issue, we took the thread of secret codes and tugged at it. We found computer hackers and made-up languages, machine learning and medical data. But the string kept running, unspooling deeper into nature and further into the past: molecular signaling, genetics, even other universes. We found ourselves considering James Gleick's observation that "information is what our world runs on: the blood and the fuel, the vital principle."

If he's right, then should we be surprised that protecting and promulgating information is the first order of business, for everything from neurons to nebulae?

Welcome to "Secret Codes."

—MS

"The mark of the entanglement of our universe with others is preserved somewhere in today's sky."

LAURA MERSINI-HOUGHTON
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Secret Codes

STORIES HIDDEN AND REVEALED

TENNIS TELEPATHY Mike Bryan (left) and Bob Bryan (right) at Wimbledon, 2013. "We use code words," says Mike.

The Secret Language of Tennis Champions

How identical twins Mike and Bob Bryan serve science

BY ERIC HANSEN

IT'S A WARM SUMMER afternoon in New York City, and Bob and Mike Bryan are hitting the fuzzy covers off tennis balls, their looping forehands and backhands mirror images of one another. The identical twins are warming up for the U.S. Open on one of the trademark blue courts in the Billie Jean King National Tennis Center. Playing singles against each other, Bob hits a soft volley. Mike returns it with a hard shot at Bob's head and calls out, "Velveeta." Cheesy shot.

PHOTO BY ADRIAN DENNIS/AFP/GETTY IMAGES

The Bryans take their customary position beside each other and face their coach David Macpherson and practice partner Georgy Chekhov. Although Bob is two inches taller and a leftie, the lanky, brown-eyed Bryans appear to be clones of one another. They glide across the court, perfectly in sync. A low ball sent down the middle does nothing to stymie them. Bob knows instinctively that Mike's got it. Mike rifles a shot down the center.

Practice ends and the twins walk in stride toward the stands, where they sign autographs. Chekhov, marveling at the brothers' skill, says to me, "They just feel each other out there. It's at the DNA level."

That's something that fans, tennis commentators, and competitors have been saying about the Bryans for over a decade. The Camarillo, California-born 35-year-olds have been the number one team for nine of the last 11 years. In 2012 to 2013, they won four consecutive Grand Slam tournaments and the Olympic gold, an unprecedented feat that led to a new record, the so-called "Golden Bryan Slam." It's impossible not to ask: Do these guys possess some sort of Twin ESP?

The short answer, alas, is no. The long answer is, well, sort of. Over the past four decades psychologists, linguists, and neuroscientists have developed a better understanding of the ways that twins like the Bryans communicate with each other. They have come up with the term "cryptophasia" to describe a secret language that twins share as kids. While scientists question whether cryptophasia constitutes a discrete language, they agree it offers a provocative look into the birth and development of language itself. Who knows? It might even offer a key into the secret of the best doubles players in tennis history.

LIKE MOST IDENTICAL TWINS, Mike and Bob played in their own world from the time they were toddlers. Only in their case, their world was tennis. "They started playing right in the crib," their father Wayne says. He and the Bryans' mother Kathy, who co-owned a tennis club in the 1980s and '90s, put balls and racquets in their crib and had them hitting balloons across the living room sofa as soon as they could walk. "There were gradual undulations along the way, but their progress was pretty darn identical," Wayne says. At age 6, they won a tournament for 10-year-olds, and pretty much every kid tournament in California and the nation after that, trading the number one spot whenever they played singles.

But their personal lives didn't blossom as smoothly as their tennis skills. When the twins were young, teachers worried about them spending too much time together. "Some doctor told my mom, 'You gotta separate twins at a young age so they develop their own identities,'" Mike says. "So my mom put us in different rooms." The Bryans sobbed so uncontrollably that their parents relented and let them sleep in the same room, often in the same bed. They stopped crying.

They also developed a language all their own, which lasted until they were 6 years old. "They didn't have long sentences, just little phrases, 'mamam inim,' that sort of thing," says Wayne. Neither Bob nor Mike nor their father could dig exact phrases out of their memory banks. "They knew what they were saying but none of us did," Wayne recalls.

Nearly 40 percent of identical twins develop a secret language as kids. Cryptophasia comes from the Greek *kryptós*, meaning hidden, and *phánai*, to speak. It also goes by "idioglossia," "secret language," "*Eigensprache*," "twin talk," and "autonomous language."

Examples are numerous. Kristy McGowan, an author and knitwear designer in Brooklyn, says she spoke a secret language with her fraternal twin sister Margit, tidbits of which their father was able to record. "We had full conversations," she says. "Even today, my sister will send me a picture of her dog, napping on his back, feet in the air, and the subject will be 'illet.' Illet means the end, no more, there's no coming back."

The most famous example of cryptophasia is identical twins Ginny and Grace Kennedy from California. A documentary and many articles, including two 1970s features in *Time* magazine, captured the private lingo of the twins who called each other Poto and Cabengo:

> "Pinit, putahtraletungay" (Finish, potato salad hungry)
> "Nis, Poto?" (This, Poto?)
> "Liba Cabingoat, it" (Dear Cabengo, eat)
> "la moa, Poto?" (Here more, Poto?)
> "Ya" (Yeah)

"What you find is that the words are approximations of adult language," says Peter Bakker, professor of linguistics at Aarhus University in Denmark, author of what remains the deepest and widest study of cryptophasia, "Autonomous Languages," published in Italian twins research journal *Acta geneticae medicae et gemellologiae* in 1987.

The morphology of cryptophasia appears to be straightforward, no matter whether the twins live in Russia, Germany, or Britain. "In none of the languages can any marking of tense-mood-aspect auxiliaries or verb particles be found," he writes. In other words, "endings are always dropped," Bakker says. "Goes becomes go, for example."

The sentence level offers perhaps the most unique deviation. "What happens in these languages is that the syntax is completely unlike the parents," Bakker says. Nothing is fixed. Nouns can precede verbs and vice versa according to no set rules. If there's a pattern, it's only that the most important or salient elements in a sentence often come first. "Olol, mama haja wausch olo hapn," goes an example of cryptophasia from Germany. It transliterates to "Rudi, Mommy good meat Rudi food," meaning Rudi, mommy wants to give you good meat to eat.

Cryptophasia arises in twins of normal intelligence and generally starts if a pre-formed model language such as English is largely absent, either because of parental neglect or simply because the twins spend so much time together. Between 1 year and 18 months, when children would typically learn a native language, the twins learn from each other instead. One twin makes a mistake, the other repeats it, and the standardization or so-called fossilization of these mistakes hurries along because both children are at the same stage in their language development and are equally eager and prepared to embrace the mistakes. Some words might be onomatopoeic. Others might be purely invented. The majority are perturbations of the ambient language, like the English the twins might hear when their parents are around. Eventually these misinterpretations stop being mistakes and become a common element of twins' grammar and vocabulary.

Some language scholars have wondered whether cryptophasia offers a window into the birth of language. Because identical twins share the same genes, cocooned in their own world, cryptophasia cracks open the long-running debate over whether human language springs from innate neurological mechanisms or is shaped by the environment in a more tabula rasa brain.

Unfortunately, linguists haven't made a ton of progress. "No one knows to what extent, if at all, the development of individual children's linguistic abilities recapitulates the evolution of language in the human race," writes linguist Guy Deutscher in *The*

IN SYNC Mike plays a shot at the 2013 Australian Open, as Bob looks on. The twins won the tournament.

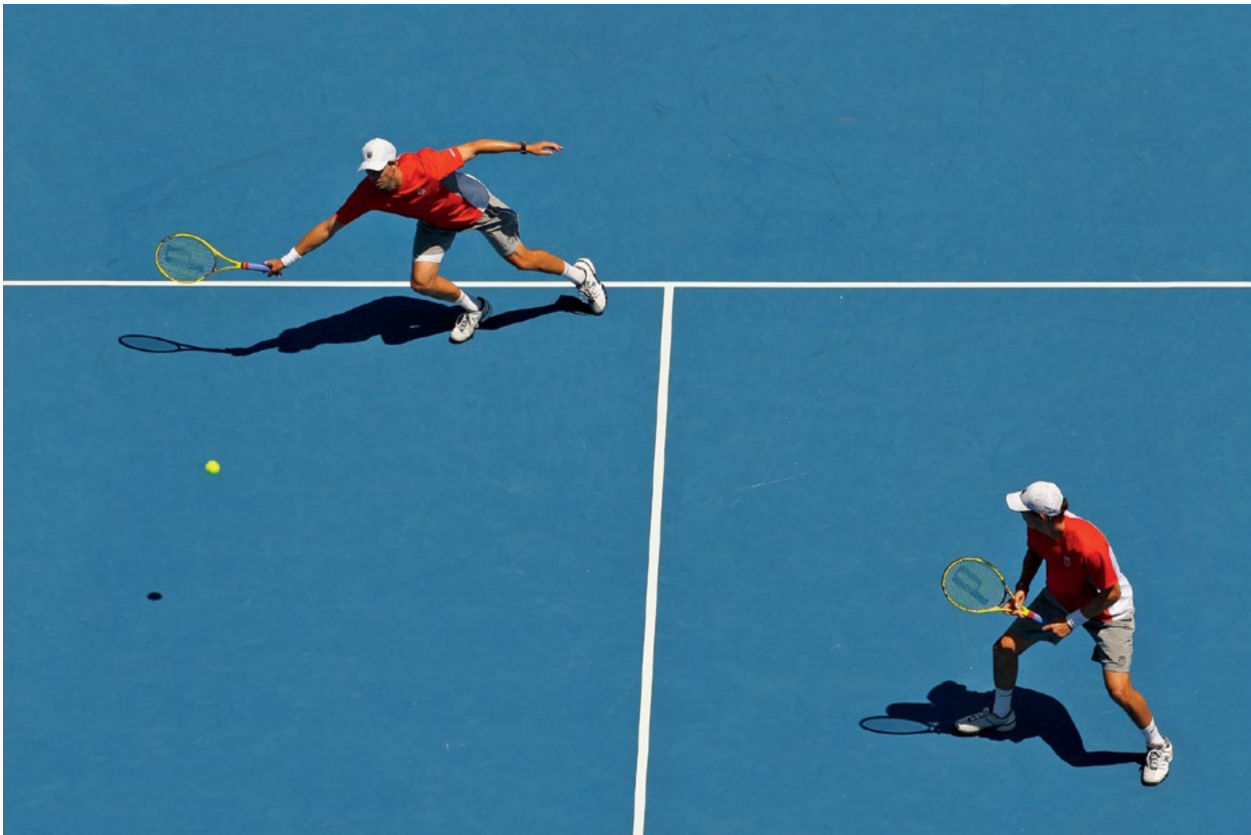

PHOTO BY SCOTT BARBOUR/GETTY IMAGES

"Other teams have unique terminology, but they have another language."

Unfolding of Language. Bakker is willing to dream a little. Cryptophasia "may shed light on the origin of language in that the words are quite crude," he says. "Maybe when language developed it had some structure like this."

James R. Hurford, an emeritus professor of general linguistics at the University of Edinburgh, and author of *The Origins of Grammar: Language in the Light of Evolution*, says he is intrigued by cryptophasia. "The best kind of evidence for what early language might have been like is where the kids depart from the adult model," he says. Cryptophasia, with its "short sentences, probably with typically just one noun phrase, no inflectional affixes, and simplified syllable structure," could represent words that "come naturally to humans in situations where they have to make up the code for themselves, without inheriting it culturally from a previous generation."

Jennifer Ganger, professor of psychology and head of the Twin Lab at the University of Pittsburgh, worked for nearly a decade on a study of twins that wasn't directly about cryptophasia, but did try to determine the heritability of language skills. She compared fraternal and identical twins, looking for similarities and differences between when they created words, and when they put words together in combination, asking parents to keep a daily log. Her take-away was that the environment was more important in determining when twins learned their first words, and genetics were more important in determining how and when twins linked those words according to a coherent grammar. "Even though I do think there's this innate grammar system that we depend on and are born with, we need other people to develop it," she says.

In that way, cryptophasia provides a glimpse at the evolution of language. Its rudimentary words give way to a wider language shaped by the world outside. It's a pattern reflected in cryptophasic twins themselves. In most cases, their private language begins to disappear when the twins enter school, interact with other kids, and immerse themselves in the more powerful lingua franca. Such was the case with the Bryans, who fully embraced English at the urging of professionals sometime around kindergarten. "We stopped speaking our alien language when we went to speech therapy, when we learned English," Mike says.

WHILE CRYPTOPHASIA MAY VANISH with childhood, the Bryans raise the intriguing possibility that it blossoms into a new alien language in adulthood. (They have yet to be studied in any place other than tennis labs.) "Other teams have unique terminology," says Macpherson, the Bryans' coach. "But they have another language."

Beginning in their teen years, Mike and Bob minted their own words for various shots and strategies. They offer a select glossary:

> "Chuckie": serve the deuce court, poach the return of serve.
> "Nestie": hit a high-bouncing serve out wide, guard the double's alley.
> "Linnie": hit the return down the line.
> "Burgie": slice the serve wide.

"Most teams strategize between points and are talking for sometimes up to 25 seconds," Mike says. "That breaks up our flow." To keep their rhythm, "We use code words. We've played so many matches together that we say one word and it speaks volumes."

In the competitive world of sports, having a shared language bestowed by common genes certainly has advantages. It grants twins the ability to read each other's non-verbal signals and act on them. "Coordinated performances is a phenomenon that we see unmistakably in twins," says Nancy Segal, professor of psychology at Cal State Fullerton and author of *Entwined Lives* and *Born Together, Reared Apart*. You can see the mind-meld in twin boxers like Oscar and Javier Molina sparring against each other, twin sprinters like Jonathan and Kevin Borlée racing each other, and twin skiers like the Mahre brothers bashing gates side by side. Segal recalls one pair of twins, professional basketball players Brook and Robin Lopez, feeling that they always just had a sense of what would come next. Similarly, Bob and Mike say they instantly know where the other will hit even before he swings, based on his strategy, his body language, even his mood.

"Doubles is all about movement," Mike says. "It's like you have a rope around your waist. You're always plugging holes. If Bob's nervous, I know what to say to him, when I should be positive, or not say anything at all. What gives us an advantage over most teams is having that kind of unspoken communication."

Bob adds, "One of the reasons that doubles takes so long to master is because it's such a complex sport. Because we're twins, and we've been around each other so much, we don't have to work on those sort of intangibles. We have our unspoken language. In some teams, you can see a clear-cut leader. With us, we play the best as equals, when we're not telling each other what to do, when we're not speaking too much, when we're using our twin telepathy of sorts."

Having a genetic advantage, however, is sometimes no match for Mother Nature, or, as Bob says, "Mother Tennis." In August, after winning four straight Grand Slam tournaments, the Bryans lost in the semi-finals at the U.S. Open. The twins, though, with an overwhelming win-loss record in 2013, will finish the year ranked number one, their fifth consecutive season at the top of the doubles tennis world.

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Beyond the Horizon of the Universe

Want to see evidence of other universes? Just look up

BY LAURA MERSINI-HOUGHTON

F**OR TWO WEEKS EVERY** summer, my parents rented a holiday apartment by the beach in Vlora, an old coastal town along the Adriatic. It was known as Aulona in Greek and Roman times, and was a special place to visit, even during 1980s communist Albania. Aulona's spirit, imprinted on the traditions, superstitions, and landscape of the place, floats outside of time. The town is guarded by a rugged terrain of high mountains, turquoise waters, and black rocks, which blend into silence at sunset. It is a place to dream absurd dreams.

ILLUSTRATION BY EMILIANO PONZI

My favorite evening activity was to sit on the deserted sand alone. I watched waves linger at the soundless horizon before breaking rhythmically onto the shore. As night fell, I waited until the line dividing sky and sea blurred away and all boundaries vanished. Of course everybody knew that the world beyond the horizon was strictly forbidden to those of us behind the Iron Curtain. But, sitting in the dark, I was free to imagine. Were kids on the other side of the Adriatic equally enchanted by the edge of the sky we shared? Eventually my dad would come over and, without reprimand, sit on the sand next to me. Then it was the two of us in a hushed conversation with the sky. Before long, he would speak, telling me it was time to leave, and the gentle spell of the sea and the sky would break.

Twenty years later, in 2009, I sat with a few dozen other scientists in a room at the Kavli Institute for Cosmology, Cambridge at the University of Cambridge to watch the launch of the Planck satellite. A muffled buzz filled the room with cautious excitement. Casual conversation would be interrupted by concern over pauses in the live transmission. When the countdown began, the room fell eerily quiet, and with lift-off came deep cheers and loud applause.

Planck was on its way to measure the gentle glow of light left over from the fiery birth of our universe, called the Cosmic Microwave Background (CMB). The CMB is a detailed fingerprint that allows us to cast our gaze onto the first few moments of our universe's existence, and to shed light on some very ancient questions: Where are we from, and how did we get here? (See The Standard Model on the next page.) This March, four years into its mission, the Planck collaboration released the most finely detailed map of the CMB ever measured.[1] In its details was a bombshell: anomalies in the distribution of the CMB brightness that could not be the result of anything in our universe. Here was an empirically observed hidden code pointing to a rich and vast cosmos, in which our own universe is but one humble member. The limits of our range of exploration had suddenly grown immensely. We were at the shore of the multiverse.

Contemplating the existence of other universes is not a new endeavour. From prehistoric times to the present day, this possibility has sparked the imagination of philosophers, writers, and scientists. But for most of history, it was not an idea that was taken seriously. Philosophically, it was an unnecessary complication, one that simply pushed the mystery of our origins to a new layer of reality that was unobservable in principle. And, since a theory needs to be falsifiable in order to be scientific, many scientists did not see the multiverse as "real" science. Aesthetically, too, the multiverse was not attractive. Scientists believed nature to be simple and economical. One universe was plenty, so why bother with more? As our scientific understanding developed, however, it became clear that the multiverse is an unavoidable prediction of our theories of nature, ones that we trust and cherish: quantum mechanics, inflation, and string theory. Today, in the face of the inertia and prejudice of the past, the multiverse is finally entering the realm of serious scientific research.

If you think you might have heard this narrative before, you have. From atomists to stoics and third century Christians, from Lucretius to Descartes, from Ptolemy to Galileo and Kant, the battle between a single universe with special origins and a collection of universes each with random beginnings has been waged for centuries. A similar battle was fought over planets and stars. In the 16th century, Copernicus took the Earth out of the center of our universe, in the face of stiff resistance from both the Church and other scientists. The multiverse might be the ultimate extension of the Copernican narrative: Even the entirety of the universe is not particularly important, but sits among infinitely many other entireties.

The multiverse narrative also has its own Copernicus: Hugh Everett who, as part of his Ph.D. thesis more than 50 years ago, had the courage to publicly pioneer the first multiverse theory by applying quantum mechanics to the whole universe. He reasoned that since the universe was tiny in its earliest moments, then it should be governed by quantum mechanics. Using wave-particle duality, he took the baby universe to be a particle behaving like a quantum wavepacket. He discovered a whole family of mathematical wavepacket solutions—a family of quantum universes. Knowing that we are observationally confined to a single universe, he had to wrestle with the idea that the quantum origins of our universe grant an equal chance of existence to infinitely many other universes.

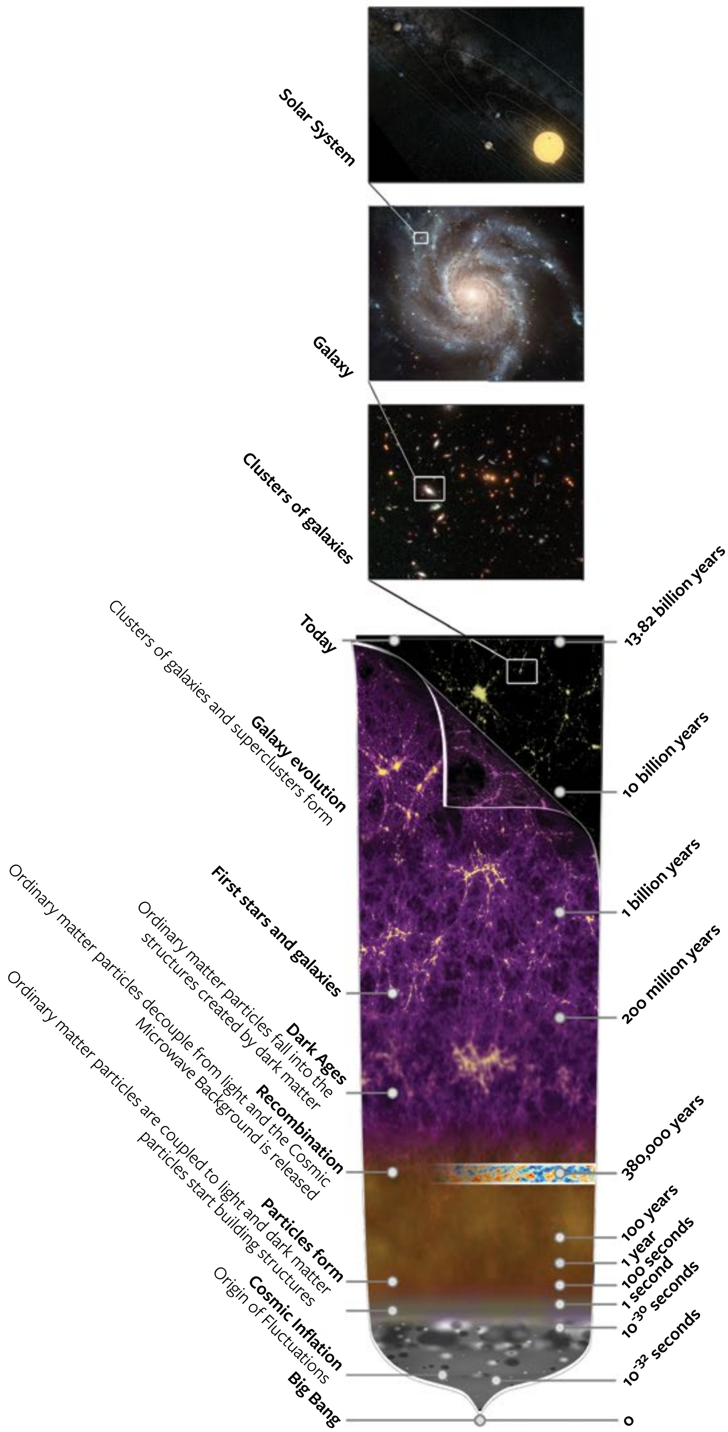

IMAGE COURTESY OF NASA

The Standard Model

In the standard model of cosmology, known as Big Bang inflation, the universe starts from a tiny domain (top), which is filled with the energy of a "particle" called the "inflaton," which must be very smooth, have a highly ordered initial state, and have very high energy. Standard estimates give the likelihood of randomly starting such a universe as 1:10ˆ10ˆ123. The standard model does not explain why the primordial universe should be so incredibly fine-tuned, or where the inflaton comes from. Like all quantum particles, the inflaton contains its own small quantum fluctuations, which induce tiny ripples in the fabric of the spacetime (about 1 part in 100,000 relative to the background). They give rise to fluctuations in the background temperature of CMB photons, known as the CMB anisotropies spectrum. The same primordial fluctuations are also responsible for seeding the formation of all the structure we find in our universe today, such as stars, galaxies, and clusters. The primordial origin of the CMB and its anisotropies spectrum, and its preservation through time, makes it a treasure trove of information about the origins of the universe. Inflationary theory predicts that the distribution of hot and cold regions in the sky and the distribution of structure must be incredibly homogeneous and isotropic. The Planck satellite can test this prediction to exquisite precision.

The mark of the entanglement of our universe with others is preserved somewhere in today's sky.

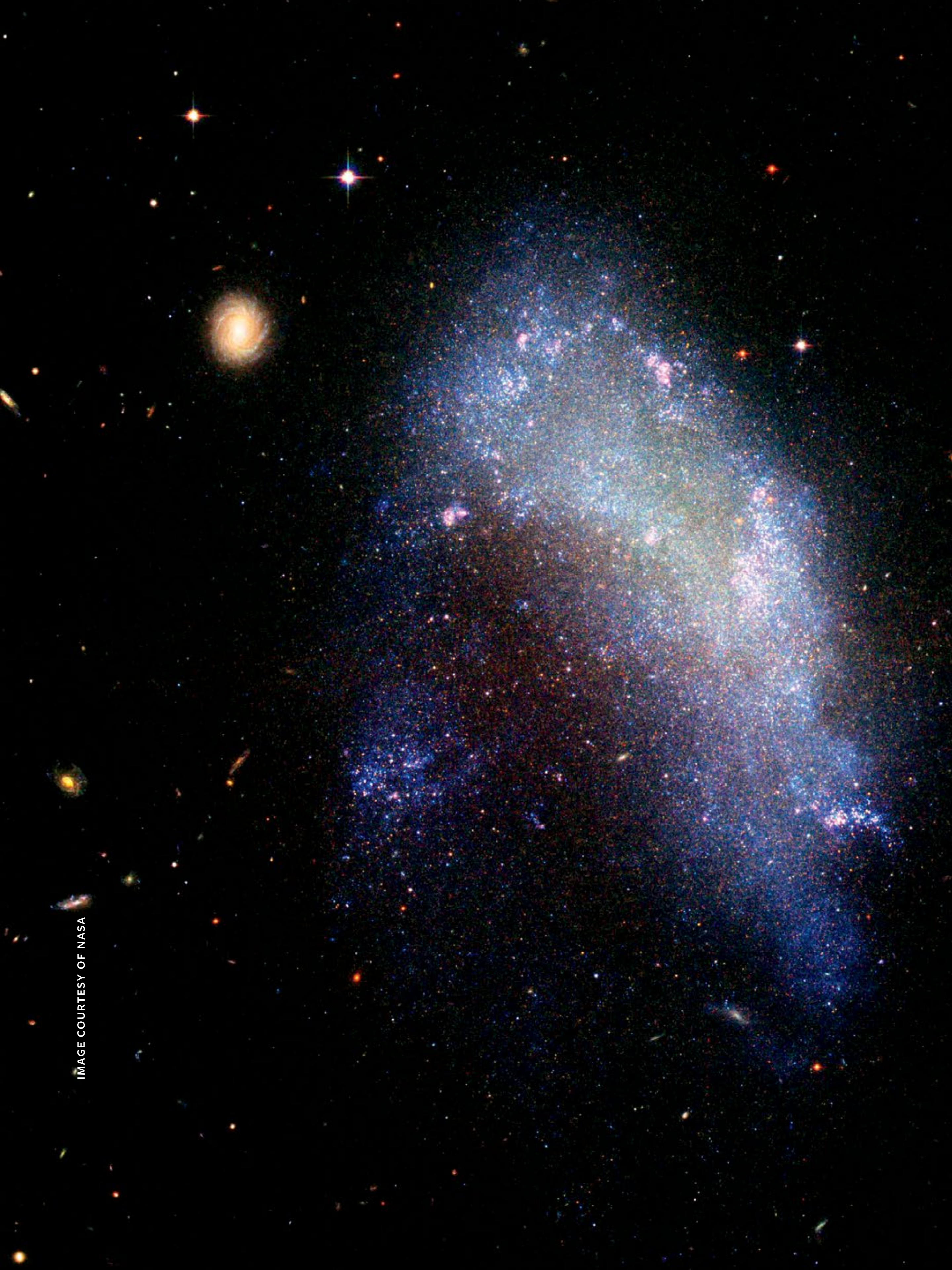

IMAGE COURTESY OF NASA

Everett was not aware of any physical criterion that would discard all the solutions except one, which led him to the conclusion that the existence of many worlds is a natural consequence of quantum mechanics. His arguments were powerful enough to draw the attention of a founding father of quantum mechanics, Niels Bohr, who resisted this interpretation to the end. Everett's academic career in physics did not make it beyond his Ph.D. studies and multiverse research became a cold case for more than 40 years.[2]

The discovery of the landscape of string theory about a decade ago marked a shift in the resistance to many-universe theories. String theory is the best candidate we have for an underlying theory of nature, and operates on an 11-dimensional spacetime. Of course, our universe appears to have only four dimensions: height, width, length, and time. One goal of string theory is to somehow get rid of the seven extra spatial dimensions, which it does by curling them up and making them invisible. This is analogous to a three-dimensional garden hose looking like a one-dimensional string from very far away.

But there are many ways of curling up seven dimensions and dumping their energy contents into the remaining four dimensions. At the beginning of this millennium, the mathematical exercise of exhausting all possible ways to do so led unequivocally to the discovery of a vast multitude of possible beginnings for four-dimensional universes. The energy profile of this multitude was named the "landscape" of string theory. Each energy valley on the landscape was a potential site for hosting the birth of a universe through a Big Bang. The multiverse was rearing its head once again, but this time at the end of a careful, decades-long theoretical exercise.

The landscape discovery was quickly declared to be a crisis for string theory. How could the leading "theory of everything" fail to predict that there was just a single universe, and that it had the characteristics of our own? The anthropic principle, which argues that our universe is the way it is because we are here to observe it, was advertised as the way out of the crisis. I had just started my first faculty job at the time, and my mentors suggested I focus my research on uncontroversial topics that would yield quick results, at least until I got tenure. This was well-meant advice, but nature's most fascinating secret had an irresistible appeal. My

The multiverse might be the ultimate extension of the Copernican narrative: Even the entirety of the universe is not particularly important, but sits among infinitely many other entireties.

discomfort with the strengthening allegiance of my field to anthropic arguments also spurred me to search for a scientific formalism through which I could calculate an answer. It was a risk worth taking.

After examining the potential pitfalls and assumptions made by previous work, I concluded that the question of why our universe was selected was meaningless unless we allowed for the possibility of a variety of different beginnings. Otherwise, the question "why did we start with this universe" was indistinguishable from the answer, "all we had to start with was this universe." The difficult step was to show how selection could be derived from the ensemble of potential states that string theory had uncovered.

I proposed that we consider a whole series of initial universes, and treat each one as a wavepacket-like particle travelling through the energy valleys of the landscape.[3,4] We could then ask ourselves: How would these initial universes evolve according to the laws of quantum mechanics? This approach avoids the need for making assumptions, and embeds the Everett multiverse into the landscape of string theory. It is also, in some ways, a familiar calculation. The application of quantum mechanics to the pool of all initial universe states is very similar to how physicists calculate how electrons travel down a wire. The energy field of the chain of atoms in the wire corresponds to the chain of energy valleys in the landscape; and the electrons' wavefunctions correspond to the wavepackets of the initial universes.

The distribution of energies on the landscape is highly disordered, like the energies of atomic sites in an insulating material like glass or an impure, defect-filled wire. Just as electrons traveling through glass get trapped at atomic sites, wavepackets of the universe traveling across the landscape get trapped at its energy sites. If the landscape had been highly ordered into a periodic chain of low-energy sites, like a perfectly ordered conducting wire, then there would be no universe. Wavepackets would not have been localized into a single energy valley. Instead, they would have been conducted all the way through the landscape, like an electron in a good conductor.

We know that our universe started in a very high-energy initial state, of about 10^{25} electron volts. Given that the primordial wavepacket wandered over a disordered energy landscape, why didn't it choose a lower-energy site? The answer is simply that, due to the quantum evolutions of the wavepackets on the landscape, high-energy initial states were the only ones that could undergo a Big Bang explosion and become large "real" universes. The evolution of these states was governed by a balance between energy obtained from the landscape, which accelerated growth, and quantum fluctuations, which decelerated growth and caused initial states to collapse into a point.

These results were considered radical at the time. But they were also encouraging, since every claim was derived from quantum equations rather than conjecture or hypothesis. For the first time we had a theory that explained why only high-energy universes like our own were selected. The theory also brought together two of the great scientific edifices of the past century, string theory and quantum mechanics, uniting them into one multiverse. But still, we did not have any testable predictions. The question became, how do you look for a multiverse?

I remember the morning when I realized that the answer was right in front of us. It was early fall in 2005, and I had spent most of the last few weeks in a state of disappointment and frustration. Every day began with optimism, and a feeling that I was close to cracking the problem. Inevitably, though, after a long evening walk spent thinking, I would come across a handful of logical flaws in the approach and become convinced the problem was unsolvable. To make matters worse, that year I had to teach a large class at 8 a.m., which is not easy for students, or for a person like myself, who works best at night. I had just finished teaching at 9 a.m. that morning and was staring blankly through a window at Starbucks when the idea hit me.

In its early moments, our universe was connected, or "entangled," to other universes. As our universe rapidly grew and shed its quantum nature, it separated forever from all the other surviving universes in a process known as decoherence. But there is a deep principle of quantum mechanics, known as the Unitarity Principle, which states that information about a system, including a quantum wavelike universe, is never lost. This principle guaranteed that the mark of the entanglement of our universe with others is preserved somewhere in today's sky.

Together with my collaborators, Tomo Takahashi and Richard Holman, I published a series of papers in 2006 called "Avatars of the Landscape" making concrete, empirical predictions for the signatures of other universes.[5-7] Most importantly, we demonstrated that the early entanglement of our universe with the rest of the multiverse added an independent source of variation to the strength of the CMB, and to the distribution of matter around our universe, known as structure. In addition, we calculated the strength of the entanglement and showed that its effect should be observable at large scales (see The Nine Secret Codes of the Multiverse).

When we published our work, we didn't dream that these predictions would be confirmed within our lifetimes. Amazingly, eight of the nine were tested within a scant seven years, and all were in agreement with the data. Just this March, the Planck satellite data successfully tested seven of these predictions in one fell swoop. The absence of Supersymmetry (SUSY) breaking at energies of about 1 trillion electron volts was confirmed by the Large Hadron Collider, in agreement with the ninth prediction. Only the Dark Flow prediction is still under debate, with two Planck team papers drawing conflicting conclusions. Taken together, these nine predictions represent a very stringent test of the

The Nine Secret Codes of the Multiverse

Tomo Takahashi, Richard Holman, and I predicted nine observable signatures of the entanglement of our universe with other universes. 1. The suppression of the overall strength known as sigma$_8$, by 30 percent; 2. The absence of fluctuations with wavelength much larger than the size of the universe, leading to an asymmetry of structure between the north and south hemispheres; 3. The alignment of the CMB along its longest-wavelength harmonics, called "the Axis of Evil"; 4. The suppression of the power of the longest-wavelength CMB harmonics corresponding to wavelengths of order 10^{25} m, roughly the size of the universe; 5. The existence of a large region in the Southern hemisphere nearly empty of structure, taking up to about 10 degrees of the sky, at a distance about 8 billion light years away, called the "Cold Spot" or "Giant Void"; 6. The spectral index of the CMB, which measures the contribution of every frequency of fluctuation, should vary with distance. The standard model predicted it to be constant. 7. An enhancement of CMB power at higher harmonics corresponding to wavelengths of order 100 Mpc (the size of a galaxy) or smaller; 8. The "tilting" of the gravitational potential of the universe, giving rise to a uniform flow of structure in a particular direction, called the "Dark Flow"[8]; and 9. The failure of the Large Hadron Collider to detect the breaking of an underlying symmetry of nature known as Supersymmetry (SUSY) at TeV energies. We predicted that the energies at which SUSY breaks are at least 100,000 times higher than the Higgs energy.

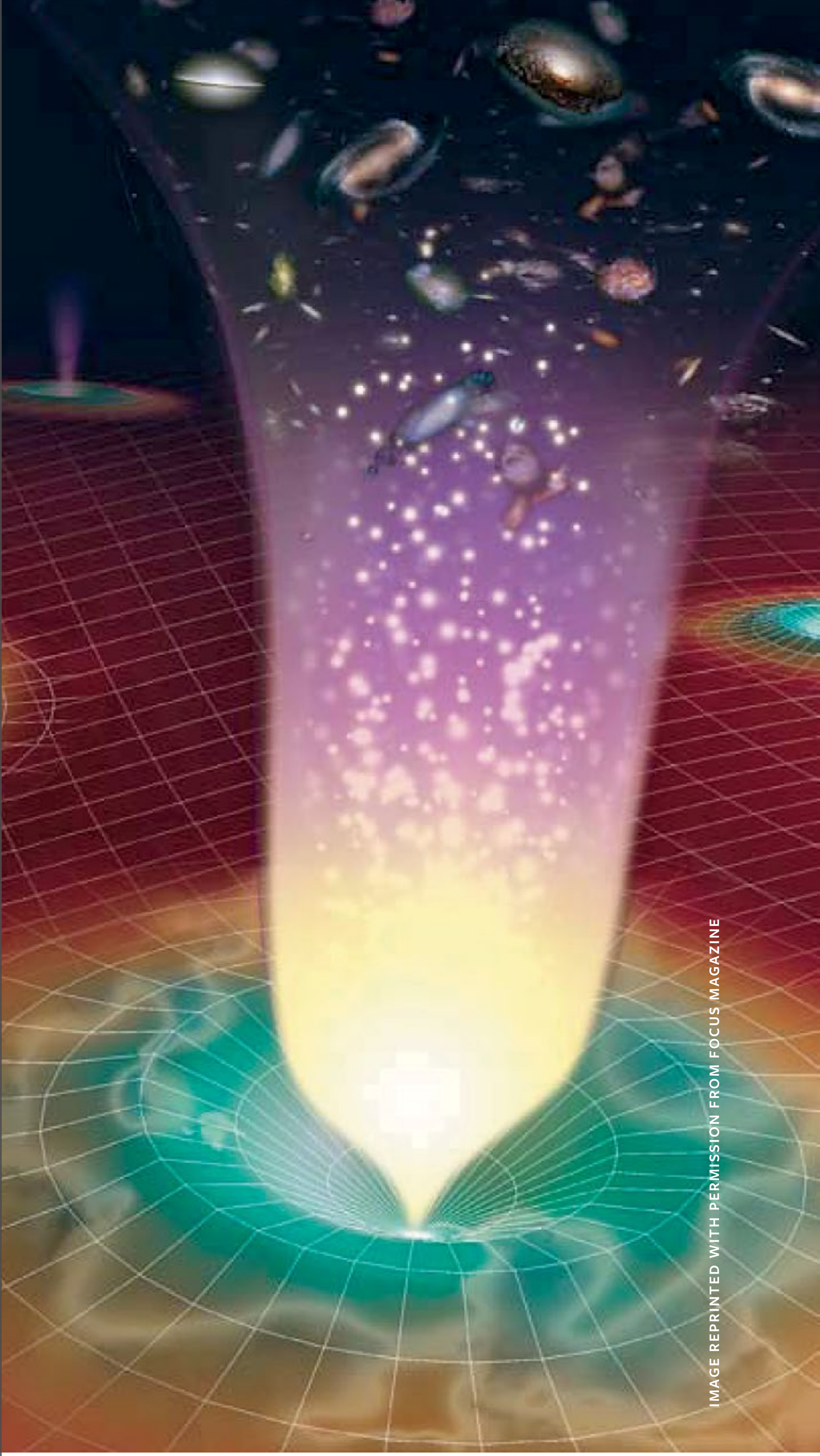

IMAGE REPRINTED WITH PERMISSION FROM FOCUS MAGAZINE theory, because all nine originate from a single theoretical framework. None of these predictions can be varied independently of the other eight in order to fit a particular set of data—the data must confirm them all, or the theory is ruled out.

Two previous measurements of the cosmic microwave background (COBE in 1992 and WMAP in 2007) have observed anomalies like those measured by Planck, but at a lower level of confidence. But it may still turn out that the Planck anomalies are overestimated. If that turns out to be the case we will be back to square one. If the anomalies are confirmed, however, we will have achieved something remarkable. Not only will we have found evidence for other universes, we will also have performed the first tests of string theory, which we used to describe the landscape. More broadly, the existence of multiple universes will demand that we revisit and confront some of our most cherished notions of the cosmos and develop a new ontology of reality: Do all universes live on the same underlying spacetime fabric? Was there a notion of time before our Big Bang? Can we detect universes that are not entangled with ours? What determines the laws of nature? It will be an exciting time.

In 2013, I returned to my favorite spot in Vlora, and brought my 3-year-old daughter with me. I watched her closely. She seemed excited to be there, completely carefree, and oh so happy to splash sand and water in every direction. How stunning, I thought, how far we'd come in just a generation politically, and scientifically. The usual silence was replaced by her infectious giggles. She was not curious about what lay beyond the Adriatic, because she already knew. She had been there. And to the place after that, and the one after that, all the way across the ocean. At her age, I thought I never would. But she belongs to a different generation, one that does not accept limits to imagination and discovery. As the horizon blurred and the sea and sky merged, my thoughts turned again to broken boundaries.

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Learning to Speak Shrub

Using molecular codes, plants cry for help, ward off bugs, and save each other

BY ELIZABETH PRESTON
ILLUSTRATIONS BY ERIC NYQUIST

ENTOMOLOGIST RICHARD KARBAN KNOWS how to get sagebrush talking. To start the conversation, he poses as a grasshopper or a chewing beetle—by using scissors to cut leaves. Lopping off the leaves entirely won't fool the plants. So he makes many snips around the edges and tips of the leaves—"a lot of little bites."

A few months later, Karban, a professor at the University of California, Davis who studies plant defense communication, returns to the sagebrush and examines its leaves, many of which now have damage from real grasshoppers or beetles. However, within about two feet of the branches he clipped, leaves have been spared the worst ravages of the hungry insects. That's because Karban's cuttings convinced the damaged leaves they were under insect attack, so they sent chemical alarms into the air. Neighboring leaves intercepted and deciphered the code messages, and began prepping their own defenses against the bugs.

If plants seem silent to us, it's only because we're oblivious to their chatter. In fact, plants emit codes into the air all the time, helping them defend against insects and other threats, and in some instances serving as warnings to their neighbors. Moreover, plants can send "SOS" calls for rescue missions, and to summon predators that feed on insect invaders.

Plants speak in chemical codes—carbon-containing molecules called volatile organic compounds (VOCs). Characterized by the ease with which they enter the air, VOCs are a diverse group: plants alone make more than 30,000 varieties. Some VOCs produce familiar herbal or flower smells. Others are released only in response to a specific cue. Within seconds of being damaged, plants send out green leaf volatiles (GLVs), which we can detect too—for example, the smell of a freshly mown lawn.

Plants can send "SOS" calls for rescue missions and to summon predators that feed on insect invaders.

Humans don't get much information from VOCs. But the waves of molecules produced by a plant carry packets of cryptic messages. And just like any transmitted signals, plant-o-grams can be received, decoded, eavesdropped on, and even scrambled.

Plants send out VOCs in response to physical damage or to chemicals in insects' saliva, vomit, or egg-laying fluids. Insect bites can activate hormones within the plant, like jasmonic acid, ethylene, or salicylic acid, which increase the activity of the plant's defense genes. These hormones can also be released as VOCs to alert the plant's other leaves and branches as well as its neighboring vegetation community. In particular, Karban says, methyl jasmonate—a volatile form of jasmonic acid—seems to be "pretty potent." He also found that such communication is more effective between genetically identical plants—those that come from the same parental bushes or shrubs. And when Karban placed plastic bags over clipped sagebrush leaves and tied them up to prevent VOCs from escaping, neither the rest of that sagebrush's own leaves nor neighboring shrubs were able to crank up their resistance.

VOC messages may be meant for self or family, but plants of other species can sometimes intercept them. Sagebrush alerts can trigger defense responses in both tomato and tobacco bushes, although it's not clear how many plants can hack into other species' signals.

Moreover, plants may not always want their cries to be heard, scientists say. "It's not really in the best interest of a plant to actually tell its neighbor it's being attacked," says Amy Trowbridge, a postdoctoral research fellow at Indiana University, Bloomington. Adjacent plants are competitors, and warning a neighbor helps that plant survive while the Good Samaritan may succumb to an insect invasion. So why do plants shout anyway? Part of it may be unavoidable: The "chemical weapons" plants use to fend off bugs may inevitably leak into the air because they're volatile—so other vegetation evolved to eavesdrop. So did some predatory insects—they essentially tune in for dinner calls. Apple trees that are chewed by spider mites send out a message

To really crack plants' cryptography, scientists need to decipher the chemistry of whole ecosystems.

that attracts other mites that eat the attacking spider mites. When female sawflies lay their eggs inside the needles of a Scots pine, the tree's VOCs summon parasitic eulophid wasps that kill the eggs. Similarly, tobacco plants that are being gnawed by budworms summon parasitic red-tailed wasps that lay their own eggs inside the caterpillars' bodies, later to be eaten by larvae from the inside out.

While plants and insects evolved to exchange these chemical messages, humans are only beginning to break the code. "We don't really know how these compounds are perceived," Trowbridge says. Researchers don't yet understand how the plants collect VOCs from the air and what the minimum detectable concentration is. Nor do they know whether the molecules are absorbed straight through the surface of the leaf, or enter through its pores, called stomata. But they do know that the "listening" plants must receive and decode the message in order to set off chemical defense reactions. "Just because a plant may take up a compound doesn't actually mean anything," Trowbridge says. If the intercepted signal can't be decoded, it's of no help.

Moreover, messages could be encoded into a combination of molecules. "The bouquet that's released when you clip sagebrush contains literally hundreds of chemicals that you can measure," Karban says. He gathers VOCs in plastic bags filled with special fibers that collect the compounds and analyzes them in a gas chromatograph. However, he says that "identifying the active ingredients is really difficult." Chris Jeffrey, an organic chemist and chemical ecologist at the University of Nevada, Reno, thinks that to really crack plants' cryptography, scientists need to decipher the chemistry of whole ecosystems. "You're detecting a very complex mixture of molecules," he says, likening the phenomena to our own sense of smell. "It's not a single molecule that results in a single response."

Why should we bother to crack plant codes? For one thing, they help us understand how plants will react to environmental changes—like those expected with climate change. Scientists warn that climate change can scramble communications and destabilize ecosystems. Some signals may be amplified while others are dampened or never detected.

"A lot of volatility is dependent on temperature," Trowbridge says, so a warming planet may let VOCs enter the air more easily. Higher temperatures can also increase the activity of enzymes that manufacture VOCs. On the other hand, plants trying to survive droughts will squeeze their stomata shut to prevent water loss. Leaves with closed stomata take in less carbon dioxide, which they need to manufacture VOCs. With less VOC communication, plants might not detect alarm signals and become more vulnerable to insects, or completely succumb to them, Trowbridge speculates. But with too much VOC emission, plant populations might defend themselves too well—so insects may seek new food sources, destroying other plant species and changing ecosystems.

So the next time you are enjoying the silence in a garden alone, remember that the silence is an illusion. There is a riot of shouting going on, if only you could hear it.

ELIZABETH PRESTON is the editor of *Muse*, a magazine about science and ideas for kids, and author of Inkfish, a blog about science and cephalopods for everyone. She has also written for Slate and *National Geographic*.

The Artist of the Unbreakable Code

Composer Edward Elgar still has cryptographers playing his tune

BY MARK MACNAMARA

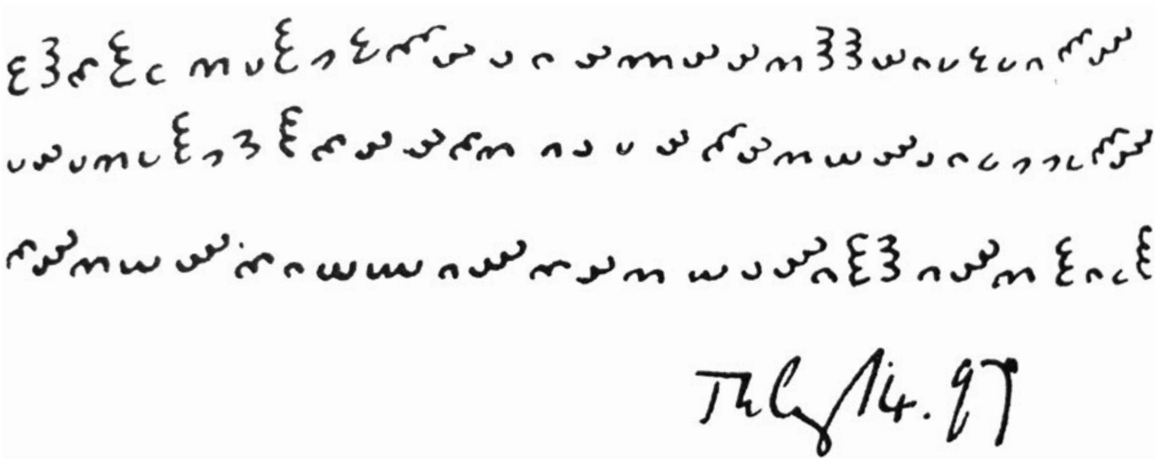
IT WAS THE YEAR of Queen Victoria's Diamond Jubilee, 1897. Through a periscope, England was sailing along in all its hope and glory. That summer Edward Elgar turned 40 and was slowly emerging as the country's greatest composer. For the jubilee he'd written *The Imperial March*, a foreshadowing of the *Pomp and Circumstance* marches that would make him famous. Earlier in the year he'd presented *King Olaf*, a foreshadowing of the choral and orchestral works that would make him great, including *The Dream of Gerontius* and *Variations on an Original Theme* (*"Enigma"*), known as the *Enigma Variations*.

In the middle of that July, Elgar was in the midst of writing a new festival work, *Te Deum and Benedictus*, working inside a large tent set up in the front garden of his house in Malvern in the south of England, where he lived with his wife and daughter. Above the tent, a flag fluttered to signify the composer was at work. Inside, amid scattered music sheets, Elgar wrote furiously, occasionally stopping to muse on a 40-mile view of the hills and heaths, and the Druid ruins that inspired him.

Elgar was ever the mercurial outsider—a tall, thin man with his bully moustache, the countenance of an ascetic atop a footballer's body—the son of a piano-tuner, completely self-taught, "from harmony to fugue," an early biographer wrote, hurried and self-divided, always in and out of love with music, always tossed between exuberance and despair, and forever obsessed with ciphers, riddles, and word tricks, not to mention his passion for "public mysteryfication," as music critic and his longtime friend Ernest Newman put it.

On July 14, following a visit the previous weekend to some family friends, the Reverend and Mrs. Alfred Penny, Elgar spun off what looked like a drawing or scribble and gave it to his wife, Alice, to attach to a thank-you note. It was intended for Dora Penny, a 23-year-old ardent admirer, who sang in a local choral group and liked to dance.

ILLUSTRATION BY EMILIANO PONZI



They'd known each for a year and a half; she was not a lover, rather an entertainment, a colorful Aquarian butterfly with which to go biking, kiting, and strolling through the bracken and harebells of Malvern; someone who could read music well enough to turn the pages at the piano bench, but with whom he could also could talk about maps, fashion, and the fortunes of the Wolverhampton Wanderers football team. He nicknamed her Dorabella.

Elgar's scribble (above) was actually a cipher. It consisted of 87 glyphs unevenly spread over three lines. It contained 24 different symbols that featured one, two, or three cusps or curves. The glyphs were tilted in what appeared to be eight various angles. In a glance it gave the sense of seagulls, or sheep, or bits of stubble. Dora looked at it, couldn't figure it out, put it in a drawer, and didn't draw it out again for 40 years.

THE SCRIBBLE, KNOWN AS the Dorabella Cipher, has never been decrypted and stands with such other famous unsolved puzzles as the Voynich Manuscript, a 240-page codex dating from the 15th century; the Phaistos Disk, an apparently Bronze-age piece of clay found in Crete in 1908; and the Zodiac Killer ciphers of the 1960s and '70s.

Countless cryptographers have ardently attempted to crack the Dorabella Cipher, employing deft math and analysis. A few quite accomplished cryptanalysts insist they have solved it. But the Elgar Society begs to differ. They're the self-acknowledged arbiters in the matter, the Union Jack flying proudly above their whistling teapot. Their argument is that any solution must decode the cipher and, at the same time, be self-evident, so that Elgar aficionados everywhere can turn to each other and agree, "Of course. Why didn't we see it?"

That the solution to the Dorabella Cipher appears so subjective contradicts the traditional notion that solving ciphers is a purely mathematical affair, leading to a single answer determined by excluding all others. But such is the nature of great riddles.

Marcel Danesi, a professor of anthropology at the University of Toronto and author of *The Puzzle Instinct: The Meaning of Puzzles in Human Life*, offers that puzzles like the Dorabella Cipher are the Sphinx at the gates of Thebes. Trying to solve them "is similar to finding the great answers in philosophy or science," Danesi says. "It's a process that leads to innovation and a deeper understanding of the world. There's a metaphysical aspect to it. Puzzles promise to order our lives, if only we can detect a deeper pattern."

Artists by nature are puzzle makers. In their work they ask us to piece together elements to reveal patterns and meanings, stirring our imaginations, promising catharsis. Elgar, a consummate artist, loved to puzzle and intrigue his friends and audiences. Whatever its solution may be, if it ever comes, the one thing for sure about the Dorabella Cipher is that it is written in the key of Elgar.

IN THE 1890S, CRYPTOGRAPHY puzzles were popular. Lewis Carroll was a puzzle master of the day, as was John Holt Schooling, a statistician and amateur conjurer of the day. His ciphers often appeared in the *Pall Mall Gazette*, "written by gentlemen for gentlemen."

In 1896, Schooling created a "Nihilist" cryptogram, a brief encrypted message, which he claimed no one would solve. In Nihilist cryptography, the encryption and decryption keys are the same; Russian Nihilists used the system against the tsar in the 1880s. Elgar stayed up one night and solved the puzzle, making notes on some sheet music for *Cockaigne*, his musical portrait of London.

Elgar was always fiddling with such things. His daughter's name, Carice, combined letters of his wife's first and middle names, Caroline and Alice. He gave violin and piano lessons to daughters of a local headmaster and used the letters in their last name, G-E-D-G-E, to create a musical cryptogram—a series of notes—and the motif for an allegretto. Incidentally, this particular bit of music is reminiscent of Robert Schumann, who was also drawn to ciphers and hid elaborate cryptograms in pieces.

Elgar's obsession with creating and sustaining mysteries would find its most famous form in his *Enigma Variations*, which debuted in 1899. The 32-minute masterpiece, scored for orchestra with organ, was a series of musical sketches, employing cryptograms, of his friends, including his friend's bulldog and Dora. "Well, how do you like that—hey?" he said to Dora when he'd finished playing the variation about her. She felt a "whirl of pleasure, pride, and almost shame that he should have written anything so lovely about me," she wrote in her 1937 book, *Edward Elgar: Memories of a Variation.* She added that she had no idea what the music "meant," although it later occurred to her that she had been a victim of Elgar's "impish humor," because in the music he caught her tendency to stammer when nervous.

The Dorabella Cipher entered the annals of cryptography almost as an afterthought, when Dora published a copy of it in an appendix to *Memories of a Variation*, remarking, "I have never had the slightest idea what message it conveys."

In fact, it is a classic, coded message. It is—or appears to be—based on a substitution system in which each glyph represents one or more letters, using a known, if obscure, alphabet. From the start, cryptographers faced two fundamental obstacles to breaking it. One is that the cipher defies frequency analysis. In any language, certain letters are used more often than others, and that particular distribution enables cipher analysis. But with Dorabella there aren't enough characters to analyze.

Then there's the historical mystery, reconciling the sophistication of the riddle with the relationship between sender with receiver. Elgar had known Dora for 20 months and had sent her two other notes in that time. There's no indication he sent her any other ciphers, either before or after July 1897. Moreover, Elgar made no attempt to conceal the cipher, giving it to his wife to deliver. Why would he send such a riddle to someone he knew only casually and who seemed to have little interest in solving puzzles? What was there to hide from Dora?

The first "solution" of consequence was offered in 1970 by Eric Sams, a wunderkind who went to Cambridge at 16, worked in British intelligence during World War II, and went on to become both a notable Shakespeare scholar and a musicologist. Interestingly, he wrote a good deal about the way such composers as Schumann and Brahms embedded codes in their music. He died in 2004.

Sams proposed a solution to the Dorabella Cipher based on the alphabet, Greek characters, and phonetic spellings. (He claimed Elgar had gotten his glyphs from a cipher manual written in 1809.) Sams devised a key to link Elgar's symbols—based on their frequency in the series, their shape and angle—to vowels and consonants. With his key in hand, he proposed that the cipher read:

> STARTS: LARKS! IT'S CHAOTIC, BUT A CLOAK
> OBSCURES MY NEW LETTERS,
> A, B (alpha, beta, i.e., Greek letters or alphabet)
> BELOW: I OWN THE DARK MAKES E.E.
> SIGH WHEN ARE YOU ARE TOO LONG GONE.

In a footnote, Sams wrote that the "train of thought" represented in his solution—"chaos, cloak, obscures, letters, alphabet, dark, sigh, absence"—along with a reference to Dora's name for him, "E.E.," made his rendering "authentically Elgarian."

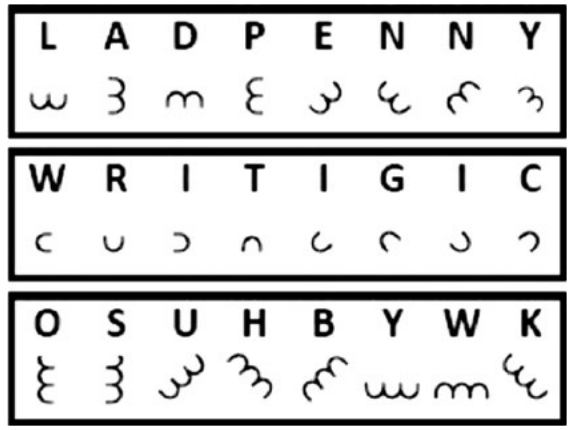
SAMS' DECRYPTION REMAINED WELL regarded, if not regarded as correct, among Dorabella Cipher sleuths for decades. The best of the Dorabella Cipher devotees were drawn together in 2007, when the Elgar Society sponsored a competition to decode the famous note. It promised 1,500 British pounds to the winner. Kevin Jones, Emeritus Professor of Music at Kingston University in London, who chaired the judging panel, explained the solution had to be methodically sound and also "glaringly obvious."

There were seven serious attempts, which followed either one of two tacks. One was a conventional decryption strategy, using substitution, and a list of arbitrary characters, which could then be translated into a plaintext message roughly matching an Elgar reference. The other approach was to construct a reasonable decryption and then "work backward" to legitimize the process, using, as Jones puts it, "any number of special cases, of conjectured errors on Elgar's part, or impossible complex procedures: combinations of shuffling, displacement, or changing keywords."

One solution that Jones found compelling was by Tim S. Roberts, an adjunct senior lecturer at Central Queensland University in Australia, and an inveterate puzzle solver. "I have an attested IQ of over 170," he told *Nautilus* in an email. "But, unfortunately, I am fairly useless at almost everything except puzzles."

Roberts approached Dorabella pragmatically. He assumed that the message was of little significance; that it was in English; and, considering Elgar's tendency to write music quickly, might well have errors. He also assumed that given Dora's lack of knowledge about ciphers the message was relatively straightforward. From that he adopted a substitution approach, but with one difference from a traditional strategy, in which there's a 1-to-1 correspondence between glyphs and letters in the alphabet. Roberts decided that two glyphs could represent the same letter, which he points out was the same technique used to decipher Mayan symbols.

Eventually, he found a key, which he deciphered by finding the name "Penny" within one set of the symbols in the cipher. His key was, "Lady Penny, writing in code is such busy work.[1]"



He applied that to his alphabet table and came up with this plaintext:

P.S. Now droop beige weeds set in it—pure idiocy—one entire bed! Luigi Ccibunud lovingly tuned Liuto studo two.

As part of his entry, Roberts wrote that the solution "is simply two thoughts put together... The first refers to gardening, which is mentioned briefly in Dora's diary entry from a few days before; the second refers to a musical composition by one of Elgar's greatest influences at this time (Luigi Cherubini). Perhaps Elgar's three greatest interests at this time were, in order, music, puzzles, and gardening—it is wonderfully exciting that this particular little note is highly relevant to all three!"

Another notable contestant was Tony Gaffney, an amateur cryptographer, who has solved several challenging ciphers. He asserted Elgar fashioned an alphabetic key for his symbols based on a clock-like diagram in one of his notebooks.[2] With that key, Gaffney maintained, the symbols spelled:

BLTACEIARWUNISNFNNELLHSYWYDUO
INIEYARQATNNTEDMINUNEHOMSYRRYUO
TOEHO'TSHGDOTNEHMOSALDOEADYA

Gaffney noted that Elgar loved and often used phonetic spellings ("My Dear Dorabellllla—How many ells long is that") and "backslang," where, for instance, the word "cipher" becomes "crehpi." Applying backslang [3]

Artists by nature are puzzle makers.

to his alphabetic rendering of the note, inserting word divisions, and taking into account phonetic spellings, Gaffney determined the note read:

> *B* (*Bella*) *hellcat ie a war using effing henshelling why your antiquarian net diminueneho am sorry you theo o'tis god then me so la deo da aye*

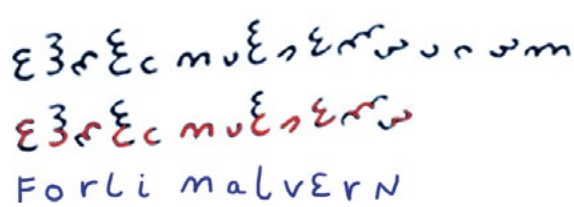
In a footnote to his solution, Gaffney wrote, "The first line didn't make much sense to me until I remembered seeing the following in a letter from Elgar to Dora Penny dated Sept. 24, 1898: "... and then some Sunday at Wolverhampton you can give us tea and fire eggs at me as of yore."

After the entries were analyzed, Professor Jones and his panel did not find a winning solution. In a statement following the competition, Jones praised some of the entrants for "impressively ambitious and thoughtful analysis." But he was little impressed that some sleuths relied on phonetic interpretations of letters and words. Those solutions, he wrote, "read as a disconnected chain of bizarre utterances, such as an imaginative mind could conjure up from any group of random letters, and make little sense." (Gaffney didn't take defeat lightly. "Who are the Elgar Society to tell me my solution is wrong?" he wrote to *Nautilus* in an email.)

Nick Pelling, a British programmer, hosts a popular website for cipher hounds, Cipher Mysteries, and wrote a self-published book, *The Curse of the Voynich Manuscript: The Secret History of the World's Most Mysterious Manuscript*. His take on why the kind of solutions proposed by Roberts and Gaffney don't work is because they offer "a convoluted attempt to decrypt the cipher itself, but no solution at all to the historical mystery. And you need to solve both at the same time."

Pelling has come to believe the Dorabella Cipher is actually a "non-mathematical stegotext"—in effect, a graphic cipher, a picture. He took Elgar's habit of starting correspondences with his address, which that summer of 1897 was his house in Malvern, which the Elgars named "Forli" after an early Renaissance Italian artist who painted angels. Using those words as a crib, Pelling came up with a beginning of plaintext:

Pelling hasn't gone further but his conviction, he wrote on Cipher Mysteries, is that "what we are looking at could well be more like Elgar's improvised steganographic attempt at a mind-reading trick than a traditional ciphertext." That is, perhaps what is "glaringly



obvious" about Elgar's note is it is simply a pictorial reference to where he and Dora crossed paths a few days earlier. Maybe she just didn't see it for what it was.

THAT DORA PENNY NEVER expressed much interest in the cipher seems strange, not least because two years later she had the opposite reaction to the musical mysteries related to the *Enigma Variations*—the theme that inspired the piece and the underlying theme throughout. She noted in her memoir, "I almost lay awake at night thinking and puzzling, and all to no purpose whatever."

Indeed, at one point she became so annoyed by it all that she confronted Elgar and demanded to know the secret. Was the theme "Auld Lang Syne?" Was it a Mozart reference? He looked at her in a "sort of half-impatient, half-exasperated way and snapped his fingers, as though waiting for me to think of the tune there and then," she wrote. "I always feel looking back to that moment, that he was on the point of telling me what it was, and then he just said: 'I shan't tell you. You must find it out for yourself.' "

Years later Dora would claim that the tune *was* "Auld Lang Syne," and Elgar had lied because the truth was he didn't want her to guess it, or anyone else for that matter, whether because "Auld Lang Syne" seemed an unbecoming solution, compared with say a Mozart reference, or because he wanted to keep all the mysteries surrounding the *Enigma Variation* secured.

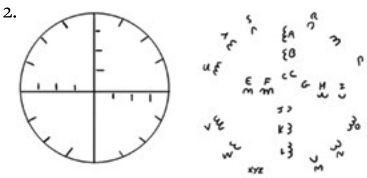
Julian Lloyd Webber, an acclaimed cellist, and younger brother of composer Andrew Lloyd Webber, is the president of the Elgar Society. He has come to see the cipher as the heart of the brilliant composer. "I think he set out to intrigue and puzzle people, knowing that they would talk about him—at the time the works were written and also long afterward," Lloyd Webber says. "There was also a mischievous side to him. He liked playing tricks on people, and one of those tricks might have been to send that poor girl that thing that was completely undecipherable and he knew it."

MARK MACNAMARA is a senior writer for *San Francisco Classical Voice*. He has written for *Salon, Stanford Social Innovation Review*, and *Vanity Fair*.

REFERENCES

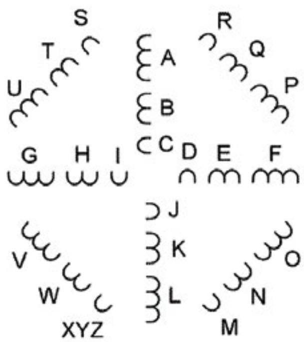
1. This September, Roberts revised his key to read, "Lady Penny, writing in a code is a way to keep busy." His new key, he explains, removes an anomaly from the ordering of the glyphs in Elgar's third line. His revised plaintext reads:
P.S. Now droop beige weeds set in it—pure idiocy—one entire bed! Luigi Ccibunud luv'ngly tuned Liuto studo two.

2.

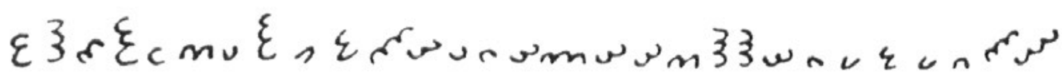


One of Elgar's notebook diagrams   Proposed alphebetical arrangement

3. Gaffney's "backslang" solution. Dorabella Cipher Key 14th July 1897



- ☐ single letter words unaltered
- ☐ two letter words reversed
- ☐ three+ all but initial letter reversed



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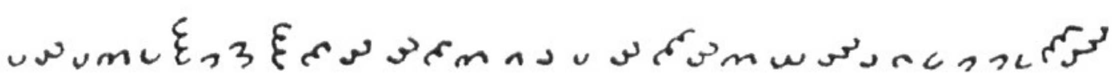

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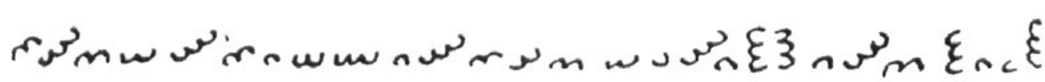

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theo				o'	tis			god			then				me	so		la		deo			da		aye	

* ??? the only word not following the backslang rules – presumably so that the 'ho' ending can also be used in the following words as 'oh am sorry..'

Safecracking the Brain

What neuroscience is learning from code-breakers and thieves

BY VIRGINIA HUGHES

ILLUSTRATION BY EMILIANO PONZI

IT'S HARD TO IMAGINE an encryption machine more sophisticated than the human brain. This three-pound blob of tissue holds an estimated 86 billion neurons, cells that rapidly fire electrical pulses in split-second response to whatever stimuli our bodies encounter in the external environment. Each neuron, in turn, has thousands of spindly branches that reach out to nodes, called synapses, which transmit those electrical messages to other cells. Somehow the brain interprets this impossibly noisy code, allowing us to effectively respond to an ever-changing world.

Given the complexity of the neural code, it's not surprising that some neuroscientists are borrowing tricks from more experienced hackers: cryptographers, the puzzle-obsessed who draw on math, logic, and computer science to make and break secret codes. That's precisely the approach of two neuroscience labs at the University of Pennsylvania, whose novel use of cryptography has distinguished them from other labs around the world, which are hard at work deciphering how the brain encodes complex behaviors, abstract thinking, conscious awareness, and all of the other things that make us human.

The Penn scientists have taken their cues from a 73-year-old algorithm that British code-breaker Alan Turing used to read secret German messages during World War II, and a mathematical sequence more famously used to break into digital keypad locks on cars. "Neurons extract information from the world and put it in code," says Joshua Gold, an associate professor of neuroscience at the University of Pennsylvania. "There's got to be some kind of code-breaker in the brain to make sense of that." Employing cryptography in the neuroscience lab, adds Gold, has provided new insights into the "gooshy hardware" that is the brain, exposing its operations as an "information-processing machine."

GOLD DIDN'T GIVE MUCH thought to cryptography until the early 2000s, when he was working as a postdoctoral fellow in Michael Shadlen's monkey lab at the University of Washington. The lab focused on how the brain makes simple perceptual decisions. How does it determine, for example, whether an object is moving to the left or to the right? The fundamental problem in making such decisions is the trade-off between speed and accuracy. The brain needs to take in enough information to make the correct decision, but not so much data that by the time it processes it all, the environment has changed and the decision is moot.

In thinking about the computations the brain might use to solve this problem, Shadlen picked up a book called *Good Thinking*, written by statistician I.J. Good in 1983. Good was a deputy statistician at Bletchley Park, the estate that served as headquarters for the British government's code-breaking unit during World War II, which was led by Alan Turing, widely regarded as one of the best mathematicians of the modern era. When reading Good's book, Shadlen was struck by a description of one of Turing's algorithms—a method for deciphering the supposedly undecipherable messages the Germans created using a machine called Enigma.

The Enigma machine looked like an oversized electric typewriter stuffed into a wooden box, with its keyboard connected to several small rotors tucked inside. Every time a letter key was pressed, the rotors turned slightly, causing the re-mapping of the pressed letter into any of the other letters in the alphabet. After the machine scrambled the message, the author could use Morse code to transmit it via radio waves. When the message's recipients set their own Enigma machine to the corresponding rotor settings (which they'd have to know in advance), they could type in that scrambled message and—presto—the machine would spit out the decoded version.

The Germans thought Enigma encryption was impenetrable; they relied on it to communicate all sorts of juicy information about their military strategy. Enigma operators working for the German navy (whose messages were the focus of Turing's work) changed the starting positions of their rotors every day.

Beginning in 1939, Turing's team developed a complex, multi-step process for decoding German messages and their contents. It was only the first step in Turing's process, however, that intrigued Shadlen and Gold, and which they thought could be adapted to brain research. That was the algorithm that Turing used to determine whether any two intercepted messages—Bletchley Park intercepted hundreds of German messages a day—had been written on Enigma machines in the same rotor state.

Turing's algorithm hinged on a genius bit of logic. He reasoned that if two Enigma machines had been set in different rotor states, then the probability of the first letter in one message being the same as the first letter in the other message would be random—or, more precisely, 1 in 26, for the 26 letters of the alphabet. The same goes for the second letter in each message, the third letter, and so on.

In contrast, if two messages came from machines set in the same rotor state, then their letters would be more likely to match. Why? Because in the German language (just as in English), some letters are used more frequently than others.

"E," for example, is the most frequently used letter in German. "That means, if you take any two German texts and just compare them character by character, you know the most likely pair you're going to find is two E's," Gold explains. With Enigma messages, the person trying to break into them wouldn't necessarily see more matching "E's," because all of the letters have been re-mapped to other letters. Still, the probability of getting *any* matched letter would be higher if the messages originated from machines in the same state.

Working with linguists, who helped him rank letter frequencies of the German language, Turing determined that two encrypted German messages created from machines in the same state would have a letter-matching probability of about 1 in 13, rather than 1 in 26.

So Turing's algorithm would essentially compare every letter in one message to every letter in the second and tally up the number of matches. If the messages were long enough, then by comparing the letter-matching frequencies he could determine with statistical certainty whether the messages had come from Enigma machines in the same state. The algorithm could also show whether the messages were too short to bother with this comparison, allowing Turing to quickly move on to the next set.

For messages that were long enough to test, a key feature of Turing's algorithm was that it summed the

Given the complexity of the neural code, it's not surprising that some neuroscientists are borrowing tricks from more experienced hackers: cryptographers.

THE ENIGMA MACHINE: Used by Germany during WWII to encrypt and decrypt messages. Every time a key is pushed, the rotors turn to display a different letter.

It turns out that Turing's methods provide great insight into how the brain assembles evidence to make decisions.

PHOTOGRAPH COURTESY OF TRISTAN APPLEBY

evidence as it was being collected—one pair of letters at a time—until enough had accumulated to make a decision about the letter-matching frequencies with a reasonable level of certainty. This method is now known as "statistical sequential analysis." If the first pair of letters matched, for example, that would be a weak piece of evidence for the hypothesis that the messages came from the same rotor state; after all, that match could have just been due to chance. If, on the other hand, the first 100 pairs of letters included 10 matches, then that would be much stronger evidence. Once the summed probabilities reached a predetermined level of certainty, Turing's algorithm could "decide" that the hypothesis—that is, that the two messages came from machines in the same state—was true.

Turing's methods were hugely successful: Winston Churchill later said that the Enigma decoding was crucial to winning the war. As it turns out, the mathematics behind the algorithm were independently discovered by Abraham Wald, an Austrian-Hungarian Jew who fled to the United States when the Nazis invaded. While Turing was decoding for the British, Wald developed some of the same math tricks to help the U.S. Army determine, for example, whether a cart of munitions was defective or worthy of shipping to the front lines.

Wald's and Turing's approach has since influenced many scientific fields, from physics and fluid dynamics to psychology and even economics. "It's all over the place," says Roger Ratcliff, distinguished professor of behavioral and social sciences at Ohio State University. Ratcliff has championed these methods for psychological experiments for nearly three decades. He thinks of human behavior as a series of decisions. "Which word to say, whether to go get a cup of coffee or a cup of tea—all of these things are little decisions," Ratcliff says. "I think this runs through everything we do."

SHADLEN AND GOLD WERE the first to apply the method to neuroscience. "It turns out to be a great insight for how the brain assembles evidence to make

There's another important similarity between the tasks of the brain and the code-breakers: Both face an unavoidable tension between speed and accuracy.

decisions," Shadlen says. Many neurons in the outer layers of the brain are selective, meaning that they fire in response to specific stimuli. Some neurons in the visual cortex, for example, fire when objects in our visual field are moving toward the left, whereas others fire when objects are moving toward the right.

The neurons aren't perfect, however; sometimes cells selective for rightward motion will fire at leftward motion, and vice-versa. In that way, Shadlen and Gold reasoned, neurons are akin to the letter pairings of two Enigma messages. A single match of letters does not provide enough evidence to say whether the messages originated from machines in the same rotor state. Similarly, any one neuronal signal is not enough for the brain to accurately determine whether an object is moving to the left or to the right. To figure this out, the brain relies instead on the aggregate activity of thousands or even millions of neurons.

In 2002, Gold and Shadlen published a largely theoretical paper suggesting that the brain uses Turing-like computations—or some close approximation of them—to weigh evidence from neuronal firings and make perceptual decisions, such as determining whether a field of dots is moving to the left or right. "Turing's work represents a form of probabilistic reasoning that the brain appears to have adopted to solve particular problems that are common to both perception and code-breaking," Gold says.

Just as the algorithm accumulated evidence in real time, the brain seems to process neuronal inputs as they're coming in, and adjust its expectations accordingly. If it receives a big batch of signals from neurons that prefer left motion, for instance, and from few that prefer right motion, then it will take that as strong evidence that the object is moving to the left. Once the inputs have crossed some threshold of certainty (scientists are still trying to understand how the brain determines that threshold), the brain makes its decision and moves on to the next.

There's another important similarity between the tasks of the brain and the code-breakers: Both face an unavoidable tension between speed and accuracy. For the World War II code-breakers, Gold says, speed and accuracy "become visceral when you think about these people realizing that thousands of lives would be saved if they could just decode these messages today." Turing designed his algorithm to balance speed and accuracy, optimizing both. That suggested to Gold and Shadlen that the brain itself performs a similar optimizing act. In the brain, says Gold, "we always knew the phenomenon existed in a host of perceptual and cognitive tasks—quick decisions save time but tend to be inaccurate, whereas taking time leads to higher accuracy but can be inefficient." The model of Turing's algorithm, Gold says, "makes a nice prediction for how the brain might deal with the speed-accuracy tradeoff." They're still testing just how that happens.

GEOFFREY AGUIRRE'S BEST BRAIN hack began late one night, at his home, while trolling Wikipedia. At his University of Pennsylvania lab, Aguirre, a neuroscientist, uses brain scanners to study how perceptions are shaped by the past. The nervous system is a master of adaptation, constantly tuning itself to particular changes in the environment. When you go into a dark basement, for example, your eyes quickly adjust to the lack of light (a change that can be painfully clear when you climb the stairs and hit the light again).

The brain's nimbleness is great for our everyday lives, but it can be a pain when designing brain-imaging studies, in which researchers take pictures of participants' brains while they experience different stimuli, such as looking at pictures of faces or hearing a series of sounds. Because of so-called "carry-over effects," the way a participant's brain responds to a picture of the color blue, for example, is slightly different if the preceding picture was blue or if it was orange.

Teasing apart these carry-over effects is particularly difficult because the brain scanner—a functional magnetic resonance imaging (fMRI) machine—measures blood flow in the brain, a proxy for neural activity. Blood flow changes relatively slowly, on the order of seconds, whereas neurons fire over milliseconds. So fMRI's sluggishness often masks neural carry-over, which can be annoying both for scientists who want to correct for carry-over effects and for others, like Aguirre, who want to scrutinize them.

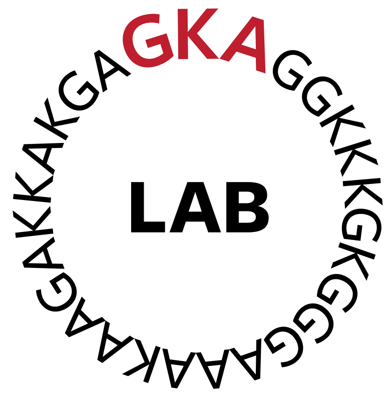
In 2007, Aguirre published a paper showing that carry-over effects can be managed by placing the experimental stimuli (pictures of different colors) in a particular order. The idea is to arrange the stimuli so that every picture appears both before and after every other picture at some point during the experiment. Then, when analyzing the data, researchers can compare the brain responses for different before-and-after combinations (blue followed by blue, versus orange followed by blue) and easily spot any carry-over effects.

That order of stimuli—in which every picture is "counter-balanced" with the previous one, without any repeat combinations—is called, in the math world, a "type 1, index 1 sequence." It works well for brain scanning because of its efficiency: It gives the shortest possible counter-balanced sequence, minimizing the participant's time lying in an uncomfortable scanner.

But for Aguirre, that sequence also had limitations. For example, the algorithm to create a type 1 sequence only works for six or more stimuli. What's more, it only accounts for the carry-over effects from one previous picture. But what if you want to study the effects of the previous two pictures, or three? This would be important because research has shown that our perceptions can be influenced not only by the last thing we saw, but the last several things. This phenomenon happens at longer time scales, too. The classic example, Aguirre says, relates to facial recognition. "If somebody moves from Chicago to Tokyo, people will describe that for a certain number of months, they find it difficult to tell faces apart," Aguirre says. "But over time you become familiar with this new range of facial appearances and then you get good at telling faces apart."

Those problems with type 1 sequences drove Aguirre to "long nights spent poking through Wikipedia," he says, laughing. He read page after page on the principles of discrete mathematics and graph theory. One night, he stumbled on the page for de Bruijn sequences, a large category that includes the type 1 sequences Aguirre was already familiar with. "De Bruijn sequences are this whole world of sequences that have a special property of counter-balance," Aguirre says. "I realized that they would be perfect for the kinds of applications we had."

To understand how de Bruijn sequences work, think of a string of letters, such as Aguirre's initials, GKA. The de Bruijn sequence arranges those three letters in a long sequence so that every possible three-letter combination is used once and only once. Aguirre made a logo for his lab's webpage to illustrate what one of these sequences looks like:



So why is a de Bruijn sequence so useful? Efficiency. If you were to write out every possible three-letter combination separately, your list might begin with:

GGG
GGA
GGK
GAA
GAG
GAK

... and so on. You'd have to type 81 letters before exhausting every combination. But as the lab logo shows, the de Bruijn sequence allows letters from one triplet to bleed into the next, allowing you to reach all possible combinations by typing just 27 letters.

Thieves can use these sequences to break electronic keypads such as those found on car doors. These generally have buttons representing the numbers 0 through 9, and pressing the right four buttons in a row unlocks the car. "If you know a de Bruijn sequence, you can cut the amount of time it would take you to crack that code substantially," Aguirre says.

Aguirre immediately saw how these sequences would be useful for brain-imaging experiments. For his purposes, the stimuli of an fMRI experiment (such as pictures of colors) are like the numbers in the car lock. The de Bruijn sequence would give him a way to put them in the right order. Just as a sequence could be assembled for any length of keycode—a three-digit code, say, or four digits, or five—a sequence could be made for any level of counter-balancing of stimuli in the imaging experiment.

The only tricky part is, a given series of stimuli has more than one de Bruijn sequence—many more. For example, if you wanted to design an experiment using 17 different pictures, with each picture counter-balanced so that researchers could later work out the carry-over effects from the previous picture, then you'd have a mind-boggling 8×10^{244} different de Bruijn sequences to choose from.

In 2011, Aguirre and graduate student Marcelo Gomes Mattar published a method to help researchers select from that massive pool the sequences that make the most sense for a particular experiment.

A researcher might have a hypothesis about how the brain responds to seeing a particular string of stimuli—such as red then orange then yellow, to use a fictitious example. Using Aguirre's methods, the researcher could choose a de Bruijn sequence that not only counter-balanced the stimuli (so that, by the end of the experiment, every picture has appeared both before and after every other picture), but also included that red-orange-yellow sequence that was key to the hypothesis. If the brain then responded in a robust way to the target sequence, the hypothesis would be proven true.

"The basic idea is that, only if your theory is right, and the person you're studying has a neural code that corresponds to your theory, only then will the neural system ring in a way that you can measure with the neuroimaging technique," Aguirre says. It's even possible to test more than one theory in the same sequence, he adds. "If that neural bell rings out at ten seconds, then maybe I'd know my first theory was right, but if the bell rings out at 15 seconds, I'd know it was the other theory."

Aguirre and another of his graduate students, David Kahn, are now using this method to test an intriguing idea about how people with autism see the world. The theory is that individuals with this developmental disorder have more sensitive and discriminating visual perception. This hypersensitivity would allow them to pick up on tiny differences in faces and scenes, but it might also make it difficult for them to adjust to a changing environment. If the theory is true, then a person with autism would show a different brain response

Thieves can use these sequences to break electronic keypads such as those found on car doors.

to a series of similar-looking faces than a person without autism. And because the researchers want to look specifically at carry-over effects from several consecutive images, the study is perfectly suited for de Bruijn sequences. If the experiment works, then the researchers will have a better understanding of the neural underpinnings of some people with autism, and with it, potentially, a new lead on finding treatments for the bafflingly complex disorder.

Aguirre has made his software freely available through his website, and other laboratories have begun to try it out. Sean MacEvoy, a neuroscientist at Boston College, has used de Bruijn sequences to investigate how the brain's visual cortex represents an object's identity and its position in space.

MacEvoy's experiment had 18 different stimuli, and he says the de Bruijn sequence worked like a charm. He plans to use it in future experiments. "With the sequence, you know you don't have any spurious biases that can cloud the interpretation of your data," he says. "I don't see a downside."

For Aguirre, cryptographic techniques will continue to help neuroscientists penetrate complex functions of the brain. Just as cryptographers have perfected ways to transform a seemingly arbitrary message into a "hash code," a sequence that can only be interpreted in one valid way, neuroscientists have learned the brain makes hash codes out of seemingly random neural firings. "Our key insight is that, effectively, the brain implements a temporal hash function on the world," Aguirre says. Providing a way to crack that world-ordering code, he adds, "is the power of this intellectual approach."

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Teaching Me Softly

Machine learning is teaching us the secret to teaching

BY ALAN S. BROWN

WHEN PYOTR STOLYARSKY DIED in 1944, he was considered Russia's greatest violin teacher. He counted among his pupils a coterie of stars, including David Oistrakh and Nathan Milstein, and a school for gifted musicians in his native Odessa was named after him in 1933. But Stolyarsky couldn't play the violin anywhere near as well as his best students. What he could do was whisper metaphors into their ears. He might lean over and explain how his mother cooked Sabbath dinner. His advice gave no specific information on what angle the bow should describe, or how to move the fingers across the frets to create vibrato. Instead, it distilled his experience of the music into metaphors his students could understand.

ILLUSTRATION BY EMILIANO PONZI

COURTESY OF NEC LABS

When Vladimir Vapnik teaches his computers to recognize handwriting, he does something similar. While there's no whispering involved, Vapnik does harness the power of "privileged information." Passed from student to teacher, parent to child, or colleague to colleague, privileged information encodes knowledge derived from experience. That is what Vapnik was after when he asked Natalia Pavlovich, a professor of Russian poetry, to write poems describing the numbers 5 and 8, for consumption by his learning algorithms. The result sounded like nothing any programmer would write. One of her poems on the number 5 read:

> He is running. He is flying. He is looking ahead. He is swift. He is throwing a spear ahead. He is dangerous. It is slanted to the right. Good snaked-ness. The snake is attacking. It is going to jump and bite. It is free and absolutely open to anything. It shows itself, no kidding.

All told, Pavlovich wrote 100 such poems, each on a different example of a handwritten 5 or 8, as shown in the figure above. Some had excellent penmanship, others were squiggles. One 5 was, "a regular nice creature. Strong, optimistic and good," while another seemed "ready to rush forward and attack somebody." Pavlovich then graded each of the 5s and 8s on 21 different attributes derived from her poems. For example, one handwritten example could have an "aggressiveness" rating of 2 out of 2, while another could show "stability" to a strength of 2 out of 3.

Using these poems, Vapnik's computer was able to recognize handwritten numbers with far less training than is conventionally required. A learning process that might have required 100,000 samples might now require only 300. The speedup was also independent of the style of poetry used. When Pavlovich wrote a second set of poems based on Ying-Yang opposites, it worked about equally well. Vapnik is not even certain the teacher has to be right—though consistency seems to count.

Vapnik is one of a growing body of artificial intelligence (AI) researchers discovering something that teachers have long known—or at least, believed—to be true: There is a special, valuable communication that occurs between teacher and student, which goes beyond what can be found in any textbook or raw data stream. By leveraging the tools of computation and machine intuition, AI researchers are giving us a more complete picture of how we learn. They are also broadening the study of education to include quantitative, numerical models of the learning process itself. "The thing that AI brings to the table is that it forces us to get into the details of how everything works," John Laird, a computer scientist at the University of Michigan, *There is a special, valuable communication that occurs between teacher and student, which goes beyond what can be found in any textbook or raw data stream.*

told me. If there was any doubt that good teachers are important, machine learning is helping put it to rest.

The teacher-student code has its roots in the sheer complexity of the real world, a complexity that has long bedeviled AI research. Is that flat surface a table? A chair? The floor? What if it's partly in shadow, or partly obscured? After years searching for simple ways to answer these questions, the AI community is finding that the complexity of the real world is, in some ways, irreducible.

Take, for example, the problem of predicting the distribution of trees in a forest using only map data, such as elevation, slope, sunlight, and shade. Jock Blackard and Denis Dean did the original calculations in 1999, and left behind an enormous public database for other mathematicians to use. According to Vapnik, when computers were trained using 15,000 examples, their predictions were 85 to 87 percent accurate. Pretty good. But when they were fed more than 500,000 examples, they developed more complex rules for tree distribution and boosted the accuracy of their predictions to more than 98 percent.

"This means that a good decision rule is not a simple one, it cannot be described by a very few parameters," Vapnik told learningtheory.org. In fact, he argues that using many weak predictors will always be more accurate than using a few strong ones.* One approach to capturing complexity is to feed hundreds of thousands, or even millions, of points to a computer, which is called brute force learning. It works well enough, and is the driving engine behind most Big Data commercial enterprises, in which machines are set loose on terabytes of data in order to understand everything from scientific problems to consumer behavior. In fact, Vapnik developed one of the key technologies used by Big Data, called Support Vector Machines. But brute force methods are also slow, inefficient, and useless when data is not plentiful, such as when studying biopsy images for cancer.

Vapnik describes privileged information as a second kind of language with which to instruct computers. Where the language of brute force learning consists of technical measurements, such as shapes, colors, forces, and the amount you spent on groceries, privileged information relies on metaphor. And metaphor can make the difference between smart science and brute force science.

To see privileged information at work, we need look no further than the human (or robot) body. The body is special because it has particular ways of interacting with its environment. A room with chairs in it is understood differently by a human with legs than by a robot without them. The thousands of points of raw data describing the room collapse into a few simple

* This is visible in baseball, where simple baseball stats like ERA and RBI are being pushed aside by a plethora of new measures, including OPS, WHIP, DRS, DIPS, BABIP, and EQA.

When your first grade teacher told you to sit down and pay attention, she was drawing on a deep understanding of how memories are formed.

ideas when subject to the constraints and demands of a physical body. If a teacher knows what it's like to have a body, he, she, or it can pass these simple ideas to a student as privileged information, creating an efficient description of a complex environment.

AI researchers are quickly learning the importance of the body, and its pivotal role in constructing and interpreting privileged information. In his lab, Laird is teaching a robot to manipulate foam blocks using language commands. The first time the robot tried to pick up an object, its own arm got in the way of its cameras, and its vision system lost track of what it was trying to pick up. It needed to be taught what its body was, and how it worked.

This may sound like the growing pains of a developmental robot, but in fact humans also need to learn how their bodies interact with the environment, and eventually start to rely on this information. Linda Smith, a psychologist and brain scientist at Indiana University, Bloomington, told me that people focus their attention like a spotlight in space. Objects in the same spotlight are linked together, or bound, in working (or short-term) memory. Smith found that children between 16 and 24 months of age could bind objects and names together in their working memory, but only if the objects were not moved around. Otherwise, the visual "noise" kept memories from forming.

What happens, though, if the child moves, rather than the object? Tony Morse, a researcher at Plymouth University in the United Kingdom, used a 53-motor robot called iCub, that is able to crawl and walk and learned much like Smith's children. Unexpectedly, it was unable to maintain the association between an object and its name when it changed its posture and looked back at an object for a second time. The robot was using its body posture to locate itself in space, reducing the complexity of its environment by physical signposting.

Motivated by this result from robotics, Smith looked for the same behavior in children—and found it. "It was a novel prediction and it was absolutely correct," she said. "It led me to a whole line of research about the role of body movement in disrupting children's memory." It turns out that, when your first grade teacher told you to sit down and pay attention, she was drawing on a deep understanding of how memories are formed. It is not something that is obvious, or something that a child would guess to be true, or that an AI researcher would program into a machine. It was privileged information.

The effectiveness of the first grade teacher's instructions was obscured by the fact that the object of the instruction (to learn) had little to do with the content of the instruction (to sit). But this is often the case. Rick Mantz is now chairman of the James Kimple Center for Alternative Education at South Brunswick High School, in South Brunswick, N.J., but he originally came to the town to coach the football team. He turned the program around immediately, after years of mostly losing records. How? "It was a character issue," Mantz told me. "We would monitor kids academically and make sure they behaved in class." Mantz had found something akin to Pavlovich's poetry and the first grade teacher's injunction. In this case, it was a connection between performance on the football field and classroom attitude. "The kids that screw up in the classroom or cafeteria will be the same ones who jump offside on fourth down in a game," Mantz explained.

Mantz could provide me with a lucid explanation of the privileged information he taught. But that is not always possible. Patrice Michaels, who directs vocal studies at The University of Chicago, spoke to me about a subtle aspect of singing that many master clinicians had believed was unteachable, but is now a regular part of singing instruction. It's called singing "vertically into the harmony," and has to do with the singer being attuned to the harmonic intention of the composer. "There is a difference in how you sing a G# note that leads to an A, and a G# that leads to an F. It's the same pitch, but depends on where you are going—how you aim it," she said. Michaels had a difficult time explaining the difference.

The potential payoffs of exploiting privileged information present an attractive target for AI researchers. Nearly 30 years ago, George Reeke and Nobel Prize winner Gerald Edelman showed that AI systems that traced letters with robotic arms had an easier time recognizing diverse styles of handwriting and letters than visual-only systems. Today, Giorgio Metta, who built the iCub robot at the Italian Institute of Technology, is counting on iCub's physicality to help it learn. "In many cases, humans use their own knowledge about actions to recognize those actions in others," he told me. "If a robot knows how to grasp, it has a better chance of recognizing grasping actions of a person," he said. Metta is going one step further, by teaching iCub to follow social cues, like directing its attention to an object when someone looks at it. These cues become another channel through which to collect privileged information about a complex world.

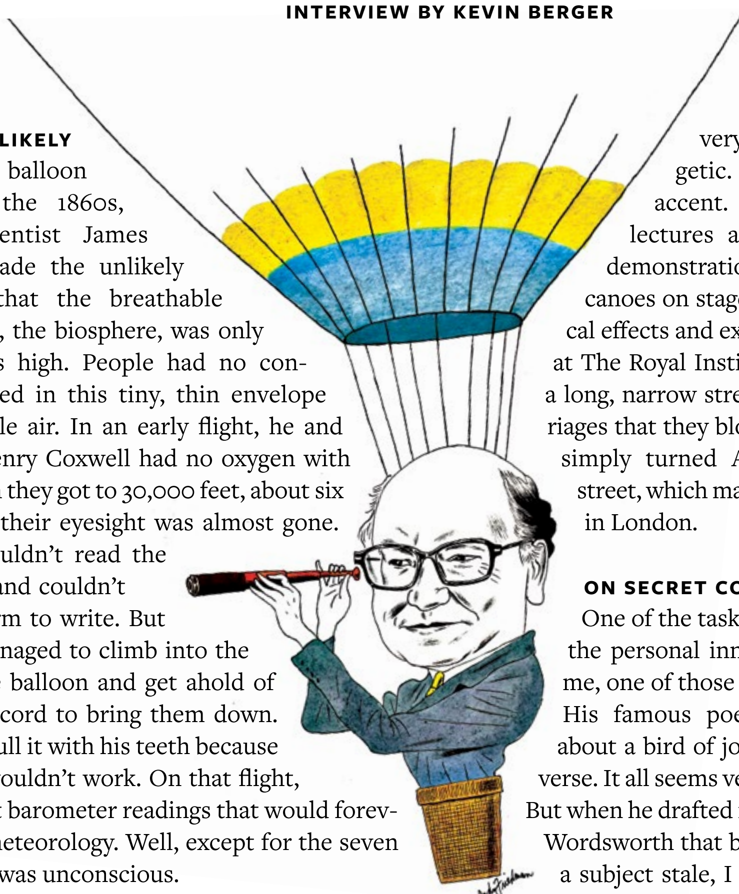
Speaking before a group of philosophers at Carnegie-Mellon University in 2012, Vapnik asked whether we can ever understand a complex world using only technical models like the ones now used in machine learning. "Machine learning science is not only about computers," he said, "but about humans, and the unity of logic, emotion, and culture." What about Vapnik's own teachers? He relayed another anecdote, this one about his music teacher. "Most of the time, I thought the teacher was talking nonsense," he said, using one of his favorite synonyms for privileged information. "But I always understood what he wanted."

ALAN S. BROWN is a freelance writer focusing on the intersection of science and engineering.

Richard Holmes

The biographer and author of The Age of Wonder *and* Falling Upwards, *about the history and majesty of ballooning, reflects on the themes in* Nautilus

INTERVIEW BY KEVIN BERGER



ON THE UNLIKELY

During his balloon flights in the 1860s, British scientist James Glaisher made the unlikely discovery that the breathable atmosphere, the biosphere, was only seven miles high. People had no concept we lived in this tiny, thin envelope of breathable air. In an early flight, he and his pilot Henry Coxwell had no oxygen with them. When they got to 30,000 feet, about six miles high, their eyesight was almost gone. Glaisher couldn't read the barometer and couldn't move his arm to write. But Coxwell managed to climb into the hoop of the balloon and get ahold of the release cord to bring them down. He had to pull it with his teeth because his hands wouldn't work. On that flight, Glaisher got barometer readings that would forever inform meteorology. Well, except for the seven minutes he was unconscious.

ON FAME

Inventor Humphry Davy was a star in the early 1800s. A celebrity! In his experiments with nitrous oxide, or laughing gas, he got not only science people to participate, but Samuel Taylor Coleridge. Lord Byron put Davy into his poem, "Don Juan," including a line about Davy's invention of the coal miner safety lamp. Davy was very small and immensely energetic. He had a lovely Cornish accent. He bounced around at his lectures and did lots of wonderful demonstrations. He built miniature volcanoes on stage and had wonderful electrical effects and explosions. When he lectured at The Royal Institution on Albemarle Street, a long, narrow street, there were so many carriages that they blocked the street. So the city simply turned Albemarle into a one-way street, which made it the first one-way street in London.

ON SECRET CODES

One of the tasks of a biographer is to break the personal inner code of his subject. For me, one of those codes is Coleridge's humor. His famous poem, "The Nightingale," is about a bird of joy, written in onomatopoeic verse. It all seems very passionate and visionary. But when he drafted it, he sent a doggerel note to Wordsworth that begins, "In stale blank verse, a subject stale, I send per post, my Nightingale." He's working on the edges of English poetry but also sees the joke about it. Coleridge also wrote a very funny letter about the "The Rime of the Ancient Mariner," where he said it's all inspired by the fact that he didn't like to set mouse traps in his cottage, because it would be inhospitable, which is of course one of the great themes in the poem, of the mariner shooting the albatross.

ILLUSTRATION BY ANDY FRIEDMAN


The MIT Press
THE OUTER LIMITS OF REASON
WHAT SCIENCE, MATHEMATICS, AND LOGIC CANNOT TELL US
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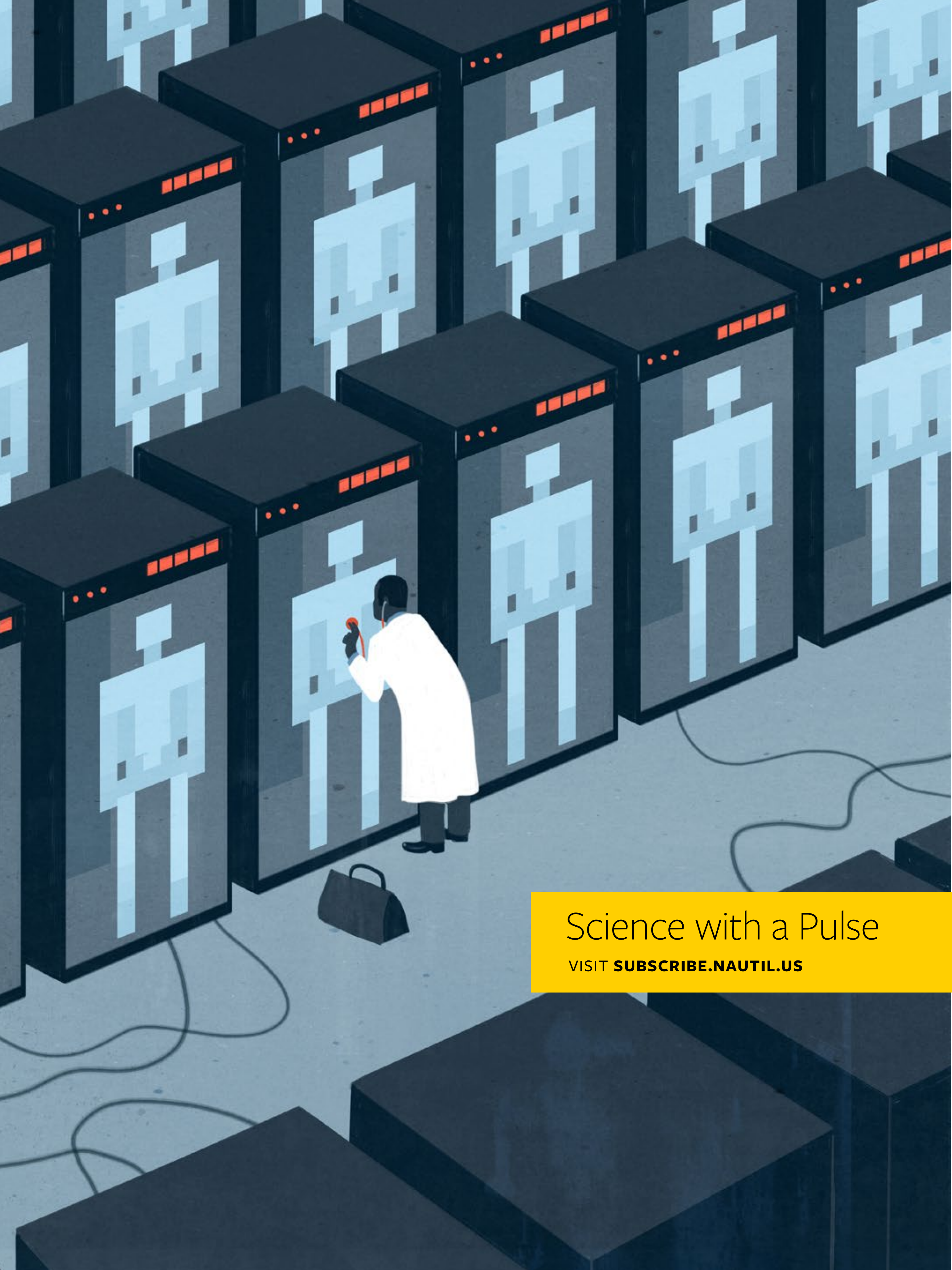
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