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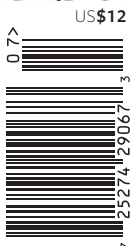
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Sound and fury

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The rules of play



Heart of the Matter

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JULY/AUGUST 2016

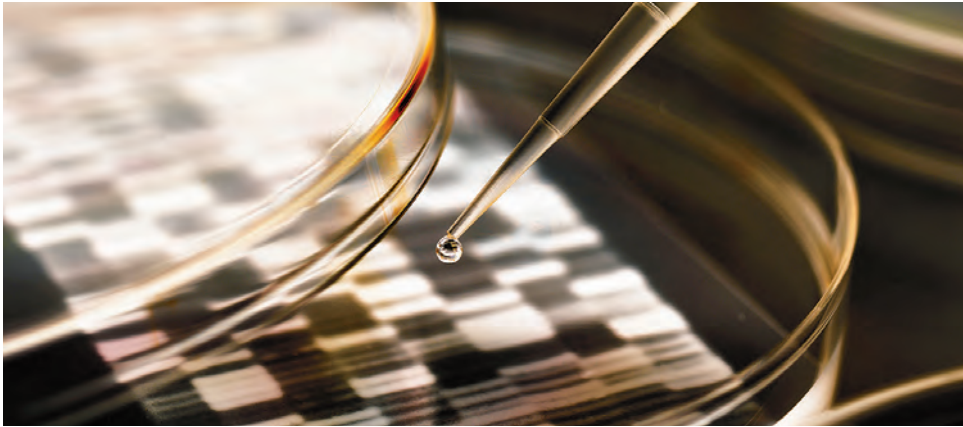
Science Connected

NAUTILUS



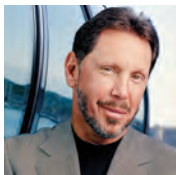
University of Southern California

A \$200 MILLION GIFT TO DISRUPT CONVENTIONAL CANCER TREATMENT



ANNOUNCING THE LAWRENCE J. ELLISON INSTITUTE FOR TRANSFORMATIVE MEDICINE OF USC

USC is proud to announce that Larry Ellison is providing a landmark \$200 million gift to the University of Southern California with the goal of disrupting conventional approaches to the fight against cancer. This momentous gift will give rise to the Lawrence J. Ellison Institute for Transformative Medicine of USC in West Los Angeles. The Institute will conduct basic and translational research in cancer and wellness, combined with outreach, an interactive care clinic and a state-of-the-art wellness program. Headed by Dr. David B. Agus, USC professor of medicine and engineering, the Ellison Institute will draw upon interdisciplinary technology leaders, researchers, physicians and scholars to change the face of cancer research. usc.edu/EllisonInstitute



Lawrence J. Ellison Institute for Transformative Medicine of **USC**

Larry Ellison is an internationally renowned entrepreneur and philanthropist who continues to shape one of the most important industries of the 21st century. His founding of Oracle Corporation—the enterprise-technology giant—established him as a visionary business leader. Mr. Ellison currently serves as Oracle's executive chairman and chief technology officer. He brings this same foresight and passion to his numerous humanitarian and sporting endeavors.

Grand Unified Self

JOHNN MAYNARD KEYNES described the deepest instincts of physics' first unifier, Isaac Newton, as "occult, esoteric, semantic—with profound shrinking from the world ..." The genius who would unify inertia and gravity suffered from a "paralyzing fear of exposing his thoughts," Keynes wrote. He could find no room for himself in the universe he created.

James Clerk Maxwell, who unified electricity, magnetism, and light two centuries later, sought to sublimate his self through his work. "I have the capacity of being more wicked than any example that man could set me," he wrote. "And ... if I escape, it is only by God's grace helping me to get rid of myself, partially in science ..."

Science's most famous unifier, Albert Einstein, elevated the role of the self by showing the profound importance of perspective and reference to physics. But he also stole time away from the subjective, human-centric frameworks that other thinkers (like Henri Bergson) had applied to it. Man was both at the center of things and nowhere to be found. "[Relativity theory] is a kind of logical system," Einstein wrote, "for describing spatiotemporal events in which the mental noumena (the will, emotion, etc.) have no immediate place."

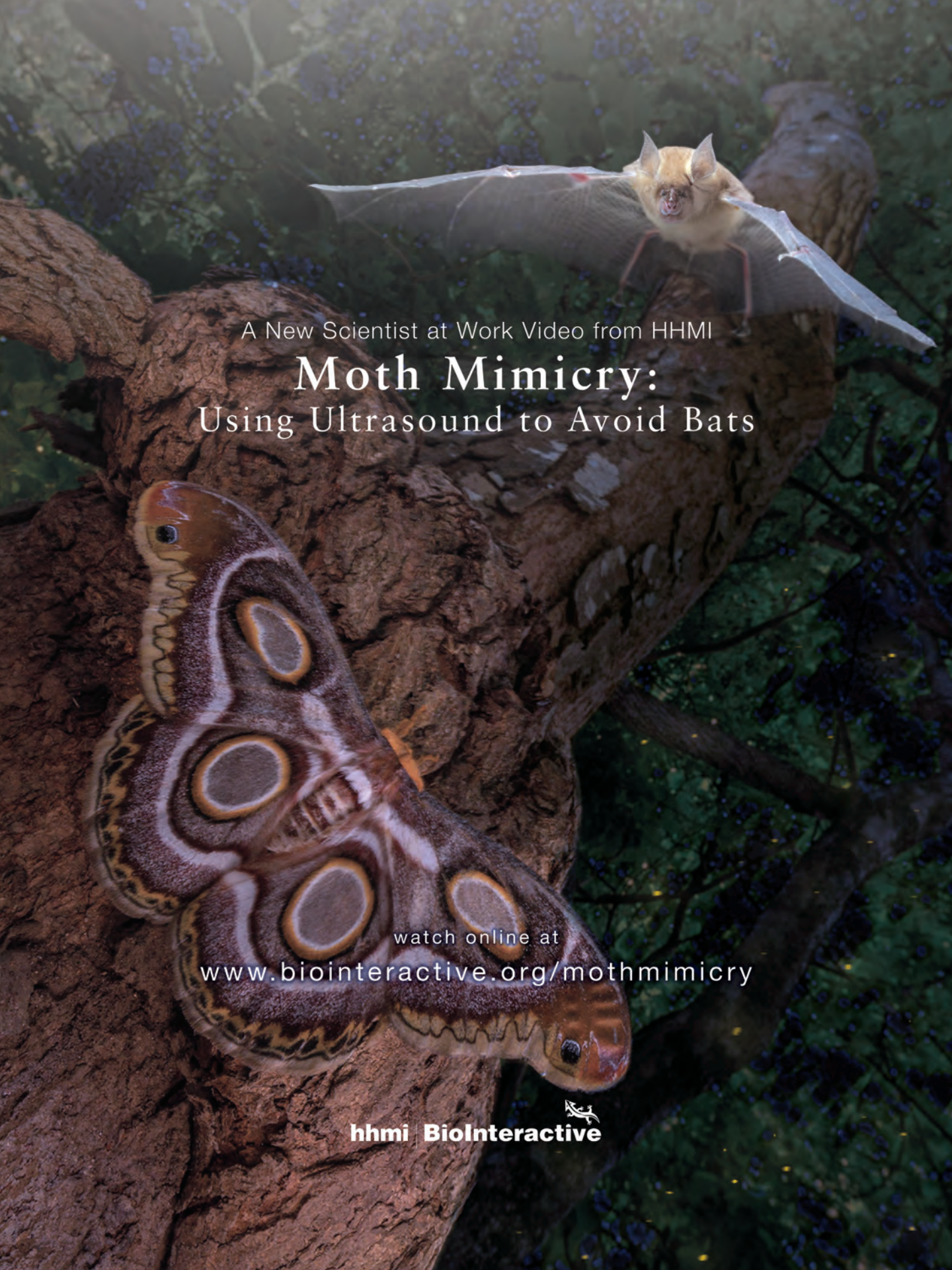
Whither the self? For Fotini Markopoulou, the subject of this issue's cover story, the question has threaded through her professional life. A founding faculty member of Waterloo's Perimeter Institute for Theoretical Physics, Markopoulou spent most of her professional life chasing the ultimate unification: merging relativity with quantum mechanics. Repelled as a young adult by the subjectivity of the art world, science attracted her with its objective truths. "Removing the person is the whole point of training as a scientist," Markopoulou says.

But in the stratosphere of theoretical physics, far removed from experimental data, Markopoulou discovered that tastemakers and subjectivity re-emerged. Politics began to swirl through the Perimeter Institute and her ideas were deemed fringe. Looking for *terra firma*, she left physics to build a wristwatch-like device called Doppel, which influences your mood through tactile biofeedback.

Having dispensed with the self, Markopoulou now spends most of her time thinking about it. In her second act, the human body is at the center of her cosmogony. "Whatever it is that you do, it has to have a context," she says. As for removing the self from science? "This may or may not be possible."

Welcome to the July/August 2016 *Nautilus* print edition.

—Michael Segal
Editor in Chief



A New Scientist at Work Video from HHMI

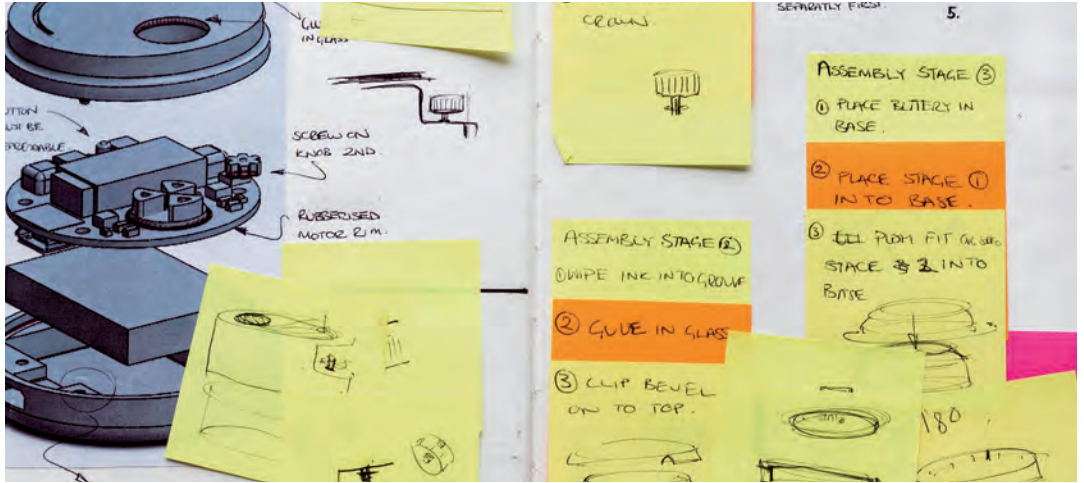
Moth Mimicry:

Using Ultrasound to Avoid Bats

watch online at
www.biointeractive.org/mothmimicry

hhmi  BioInteractive

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Noise

“Our visual system—and, with it, other sensory inputs—inform our movement in ways that bypass conscious awareness.”

—Sam Schramski, p. 42

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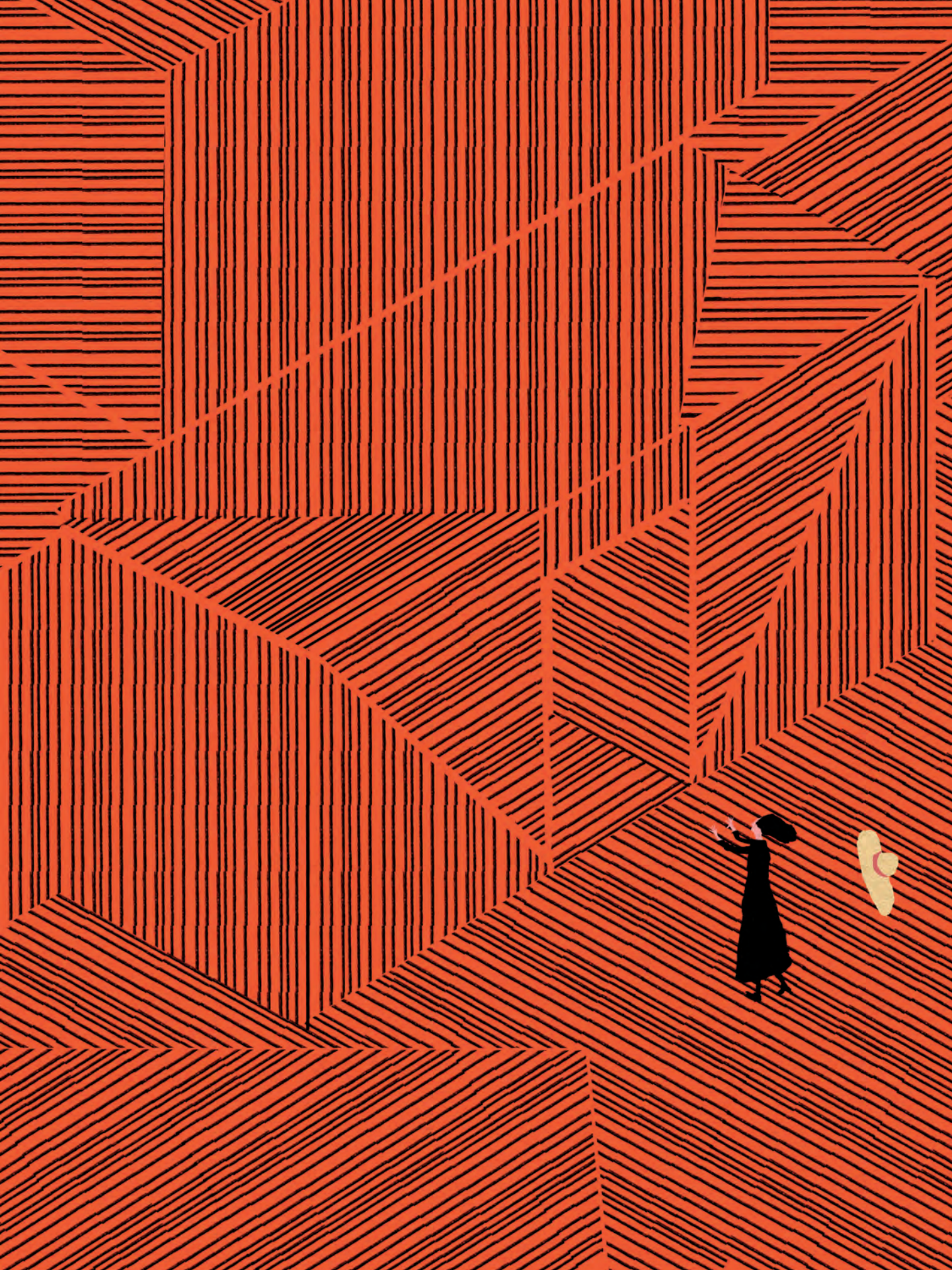
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“It’s not about winning or losing; it’s about the human bonds we form in the process.”

—Brian Barth p. 116

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Where our current knowledge
about the world ends is where
Max Planck scientists seek answers

At the threshold to the unknown



MAX PLANCK
FLORIDA INSTITUTE FOR
NEUROSCIENCE

Inspired by Daniel Wilson, David Whitney, Benjamin Scholl, and David Fitzpatrick (2016).
Orientation selectivity and the functional clustering of synaptic inputs in primary visual cortex.
Nature Neuroscience



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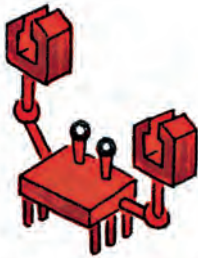
Letters

Reader responses to the May/June 2016 print edition.

“HOW TO SURVIVE DOOMSDAY”

Humans will never be able to upload ourselves to machines. The best we might do is make a copy of our brains and nervous systems. But a copy of you is not you, any more than your twin is you.

—Albeit



“THE WISDOM OF THE AGING BRAIN”

Wisdom is the practical application of experience. As I have said to my children and grandchildren, “I’m smarter than you because I have made more mistakes.” My experiences of success and of mistakes give me credibility, authority; when I provide advice, the “how” is important, but I believe the “why” is more relevant.

—Max King

If wisdom really could be passed along easily, I’d think, given millennia of human history, humanity itself would be a lot wiser than we currently are. But much wisdom seems to me to be mostly practical knowledge of how things work, both in the physical world and in society or even individual

psychology. While it is possible to impart such wisdom on others, at least partially, I think there is a lot of value in discovering such things for yourself.

—Steven Don

“BACTERIA ARE MASTERS OF TAI CHI”

That is fascinating. I never knew so much about bacteria. In addition, I am a physicist, and I worked in the industry on electronics, photonics, and micromachining. I was never sure if I was a physicist or an engineer. I now know that I am a physicist, and that I applied the principles and methods of physics to the tasks at hand.

—John Karpinski



“THE SURPRISING IMPORTANCE OF STRATOSPHERIC LIFE”

Please don’t blame the microbes. They’ve been traveling around forever. Modern agribusiness monoculture just doesn’t allow for the control systems that presumably evolved in diverse communities that keep them from becoming “rampant.”

—James Rose



CORRECTIONS

As originally published in the May/June 2016 print edition of *Nautilus*, “Paving Over the Fossil Record” incorrectly identified the man to coin the term “dinosauria.” It was Sir Richard Owen.

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

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September 22-25, 2016
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G FREELY

THE WORLD'S LEADING THINKERS EXPLORE AND CELEBRATE
THE MOST CRITICAL IDEAS OF OUR TIME.



Preludes



NEUROSCIENCE

Your Brain's Music Circuit Has Been Discovered

BEFORE JOSH MCDERMOTT WAS a neuroscientist, he was a club DJ. He saw firsthand how music could unite people in sound, rhythm, and emotion. “One of the reasons it was so fun to DJ is that, by playing different pieces of music, you can transform the vibe in a roomful of people,” he says.

With his club days behind him, McDermott now ventures into the effects of sound and music in his lab at the Massachusetts Institute of Technology,

where he is an assistant professor in the Department of Brain and Cognitive Sciences. In 2015, he and colleagues Sam Norman-Haignere and Nancy Kanwisher made news by locating a neural pathway activated by music and music alone. They played a total of 165 commonly heard natural sounds to 10 subjects willing to be rolled into an fMRI machine to listen to the piped-in sounds. The sounds included a man speaking, a songbird, a car horn, a flushing

“It’s pretty clear that music has a biological basis.”

ILLUSTRATIONS BY ROBIN DAVEY

toilet, and a dog barking. None sparked the same population of neurons as music.

When it comes to understanding subtle neurological activity, brain scans are more like magnifying glasses than microscopes. fMRI scans highlight activity in specific *regions* of the brain, but each data point corresponds to hundreds of thousands of brain cells. Until recently, scientists didn't have a way to disentangle the behavior of smaller groups of neurons. Even if music and language seemed to activate the same regions of the brain, no one knew if they activated the same cells.

The MIT team adopted a new technique to break down the fMRI data. They tried to explain the response to each of the distinct sounds at each point in the brain as a sum of a small number of canonical responses, each potentially corresponding to a different population of neurons. It was a little like zooming in on a photograph until pixels appear, and then finding a way to separate each pixel into even smaller components.

The results challenge a persistent claim that the brain processes music and language in the same way. "You have different neural circuitry that's involved in music and language," says McDermott. "There doesn't seem to be a whole lot of overlap." Could music be its own form of communication? "To the extent that music functions for communication, it's quite different from language in that it doesn't denote specific, concrete things in the world, like something you would say," he says. "But it

Could music be its own form of communication?

obviously expresses something, typically something emotional."

"It's pretty clear that music has a biological basis," he says. "The evidence is that music is a universal phenomenon. It doesn't seem to be a purely cultural convention in the way that movies are. In pretty much every culture we know of, no matter their state of development or technological advancement, there's always something you see and recognize as music. That seems to suggest that there's something in the human brain that causes groups of humans to engage in musical behavior."

—Daniel A. Gross

MATH

How Big Data Creates False Confidence

I CLAIMED that Americans have gotten more self-centered lately, you might just chalk me up as a curmudgeon, prone to good-ol'-days whining. But what if I said I could back that claim up by analyzing 150 billion words of text? A feverish push for "big data" analysis has swept through biology, linguistics, finance, and every field in between.

But there's a problem: It's tempting to think that with such an incredible volume of data behind them, studies relying on big data couldn't be wrong. The bigness of the data can imbue the results with a false sense of certainty. In the case of language and culture, big data showed up in a big way in 2011, when Google released its Ngrams tool. Google Ngrams allows users to search for short phrases in Google's database of scanned books—about 4 percent of all books ever



The problems start with the way the Ngrams corpus was constructed.

published!—and see how the frequency of those phrases has shifted over time. Since its launch, Google Ngrams has been, well, largely an endless source of entertainment—but also a gold mine for linguists, psychologists, and sociologists. They’ve scoured its millions of books to show that, for instance, yes, Americans are becoming more individualistic. The problems start with the way the Ngrams corpus was constructed. In a study published in 2015, three University of Vermont researchers pointed out that, in general, Google Books includes one copy of every book. This makes perfect sense for its original purpose: to expose the contents of those books to Google’s powerful search technology. But for sociological research, it makes the corpus dangerously skewed.

Some books end up punching below their true cultural weight: *The Lord of the Rings* gets no more influence than, say, *Witchcraft Persecutions in Bavaria*. Conversely, some authors become larger than life. From the data on English fiction, for example, you might conclude that for 20 years in the 1900s, every character and his brother was named Lanny. In fact, the data reflect how immensely prolific Upton Sinclair was: He churned out 11 novels about one Lanny Budd.

Still more damning is the fact that Ngrams isn’t a well-balanced slice of what was being published. The same UVM study demonstrated that, among other changes in composition, there’s a marked increase in scientific articles starting in the 1960s. This makes it hard

to trust that Google Ngrams accurately reflects the shifts over time in words’ cultural popularity.

Of course, this isn’t news to statisticians and linguists. Data and interpretation are their bread and butter. And when big data isn’t

seen as a panacea, it can be transformative. All it takes is for teams to critically assess their assumptions about their data rather than succumbing to “big data hubris”—even when someone points to billions of words.

—Jesse Dunietz

PSYCHOLOGY

Are Dreams Meaningful or Just Noise?



ONCE, I DREAMED I WAS at the funeral of a man who wanted each of his toes to be buried

in tiny, individual coffins.

When I woke up, I wondered, “What could it mean?” Perhaps nothing. Harvard psychiatrist Allan Hobson has argued that dreams are narratives our frontal brain areas piece together from chaotic brain signals originating from the brain stem. They’re transparent, if garbled, depictions of life’s day-to-day thoughts and concerns, not important messages from the subconscious.

But not all dream researchers agree that dreams are merely the product of neural noise. Atti Revonsuo, a cognitive neuroscientist at the University of Skövde, in Sweden, argues that we evolved dreaming as a form of threat simulation. Dreams turn out to be about ancient dangers more often than modern ones, like credit-card fraud. They also have a tendency to feature negative emotions—fearful, angry, and anxious dreams are more common than happy ones. What’s more, mental practice has been shown in over 30 sports to be as helpful as physical practice.



Post 9/11 dreams tended to have more themes of attack.

Of course, Hobson and Revonsuo could both be right. The mind might deal with the brain stem's random information like actors playing an improv game, taking suggestions from the audience and building a story, in order to rehearse for a real threat. Just because the inspiration might be random doesn't mean that resulting story needs to be meaningless.

Indeed, most people do think their dreams have some kind of metaphorical meaning. But whether they are actually meaningful—representing something important about the psyche—is a difficult question to answer because we do not know how to scientifically show that one thing in a dream really represents another in waking life, says Dan J. Stein, author of *Cognitive Science and the Unconscious*. For example, suppose Pat is beaten up in a bar fight and dreams that night of being attacked by an alligator. Does the alligator represent the attacker from the night before? There's no definitive way to answer, but some studies are suggestive.

A 2008 study, by researchers at the Tufts University School of Medicine, for example, looked at the 10 most-recently reported dreams before the 9/11 attacks and compared them to the 10 most reported dreams after the attacks, and found that the dreams post-9/11 tended to have more themes of attack, such as being pursued by monsters or wild animals. The results, the authors conclude, support the “idea that the dream image is an emotionally guided construction or creation, not a replay of waking experience.”

—Jim Davies

TWO QUESTIONS, TWO SCIENTISTS



“What is the math of morality?”

Molly Crockett

Moral psychologist and neuroscientist at the University of Oxford

As machines become increasingly autonomous, scientists are racing to boil morality down into a set of algorithms. The goal is to have artificial intelligence reliably behave at least as well a decent human being. It may seem unreachable, but psychologists are discovering a core set of equations that can describe decision-making across a variety of domains, from navigating through a parking lot, to selecting items from a menu, to giving up resources to spare another from pain. We discover these equations by inviting people to make different kinds of decisions and measuring how features of the choices influence the decisions. Just as baking a cake requires first knowing the ingredients list, then the amounts of each and in what order to mix them, psychologists have identified many of the key ingredients of morality. They're now investigating how these elements are combined, in what amounts and in what order, to produce human moral judgments and decisions. Discovering these algorithms is an important step toward building moral machines.



“What is the physics of ISIS?”

Neil Johnson

Physicist studying complex systems at the University of Miami

It's driven by the complex-systems idea that the type of emergent effects we see in a society are actually a product of multiple past and present interactions. Large datasets of social media material show that ISIS' hard-core support lies at the mesoscopic level of groups—ad hoc virtual communities. The evolution of this pro-ISIS aggregate ecosystem follows a rather precise mathematical form. Since these aggregates are leaderless, self-organized entities that change rapidly, their dynamics are remarkably close to models of bird flocks and schools of fish—individuals don't drive them. Instead of having to sift through millions of Internet users and track specific individuals, an anti-ISIS agency can simply identify the aggregates and analyze what they share to get the pulse of the entire organization. Our analysis suggests that the rate of creation of aggregates proliferates in a specific mathematical way preceding bursts of real-world attacks. Monitoring that can help predict future real-world attacks. If anti-ISIS trackers are on the lookout, a big online surge can be an early warning that could be used, along with additional intelligence, to thwart a planned terrorist action.

The Moral Argument for Doping in Sports

TO ALMOST ALL SPORTS FANS, doping in sports is an issue of near-religious importance, says Julian Savulescu. According to the Australian bioethicist and moral philosopher, fans celebrate people of extraordinary physical ability who dedicate themselves to performing an athletic feat to perfection—but when athletes augment their abilities with drugs and enhancers, fans can feel personally wronged.

It's time to wake up and smell the steroids, he says. The director of the Uehrin Centre for Practical Ethics at the University of Oxford, Savulescu has come to the conclusion that doping shouldn't be a moral question at all—in fact, he's for it. He spoke to *Nautilus* about why we are living in a “fairyland” if we think it isn't going on.

Should doping be allowed in sports?

Sport is interesting because people take sport more seriously than religion. Sport is the last bastion of our nature as human animals. People don't like cheating because it goes against everything that we needed as animals: an accurate display of people's genetic potential. That's why you want to find out who is naturally the fastest runner in the world, not the person who can run the fastest with the assistance of technology, but who was just born with the best genes.

But then doesn't that become a competition between the best chemists, rather than the best athletes?

Well, it might, of course. If you were able to amputate people's limbs and give them bionic limbs like the Six Million Dollar Man, and these limbs enabled people to run 100 meters in two seconds, it would just be a matter of who produced the best bionic limbs.



It would just be a matter of who produced the best bionic limbs.

What's wrong with illegal doping? Is it just the disadvantage it creates?

That's exactly the point. The current system enables that, because it places constraints that are impossible to enforce. There's nothing inherently wrong with allowing people to increase their red blood cell count, just as there's nothing wrong with allowing them to increase the glucose in their blood or their level of hydration. There's nothing wrong necessarily with doping. It can be wrong if it robs the sport of a significant human contribution, or it can be wrong if it's very exaggerated and dangerous to health.

Are fans deluding themselves by trusting in doping tests to ensure fairness?

We have this saying in Australia—it's “no bull,” or “no bull dust.” It's just cutting through all the crap, and then what are the real issues, what should we think, be honest, don't be a hypocrite, come to a fair decision, give everyone a fair go. And then get on with it and do it. I think there's just so much crap in modern life, and I think we need to be more honest about the way the world is. Doping is a great example: I don't know how people continue on in the fairyland, believing myths and lies. I think we should start off with being honest.

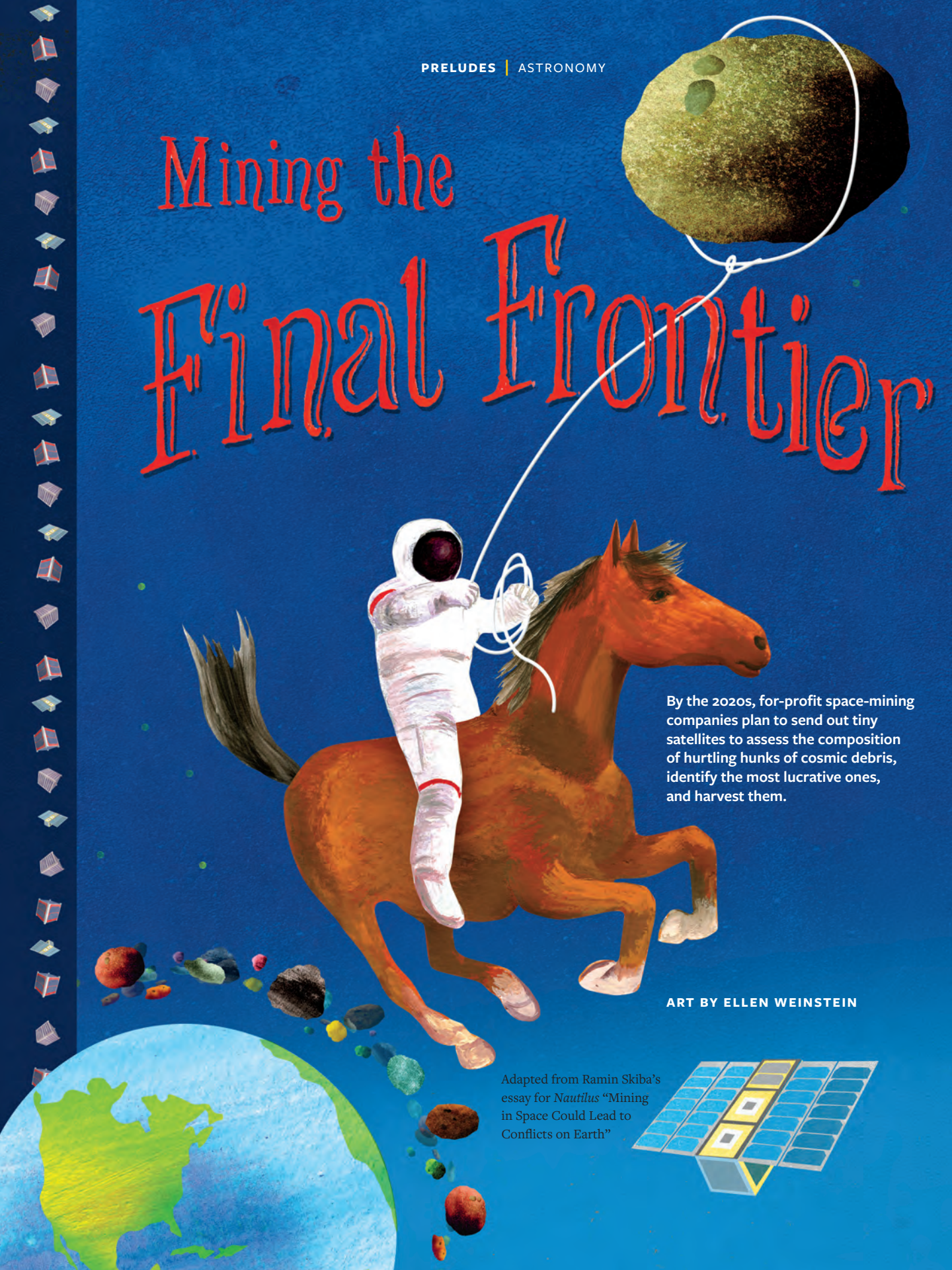
—Steve Paulson

Mining the Final Frontier

By the 2020s, for-profit space-mining companies plan to send out tiny satellites to assess the composition of hurtling hunks of cosmic debris, identify the most lucrative ones, and harvest them.

ART BY ELLEN WEINSTEIN

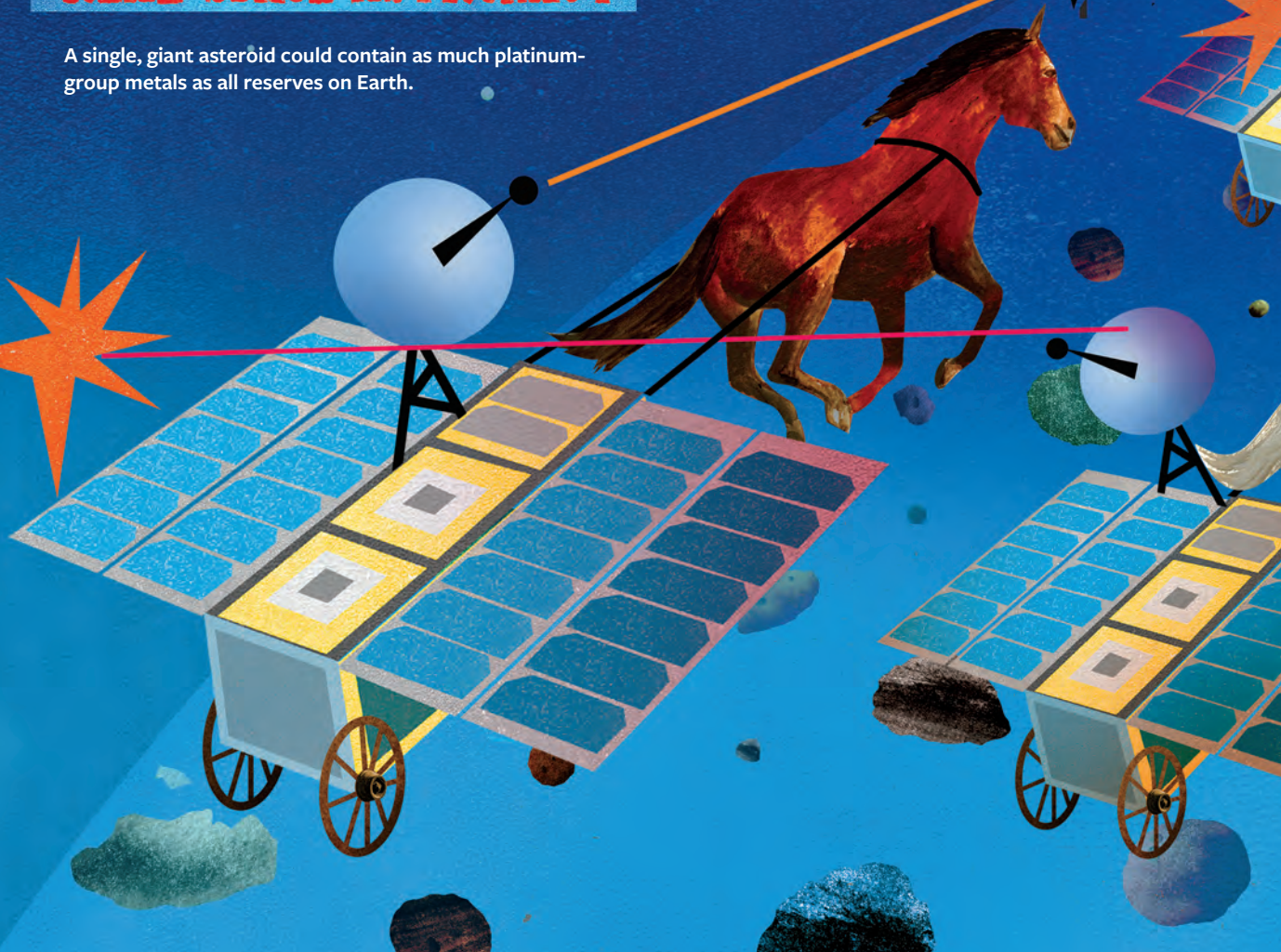
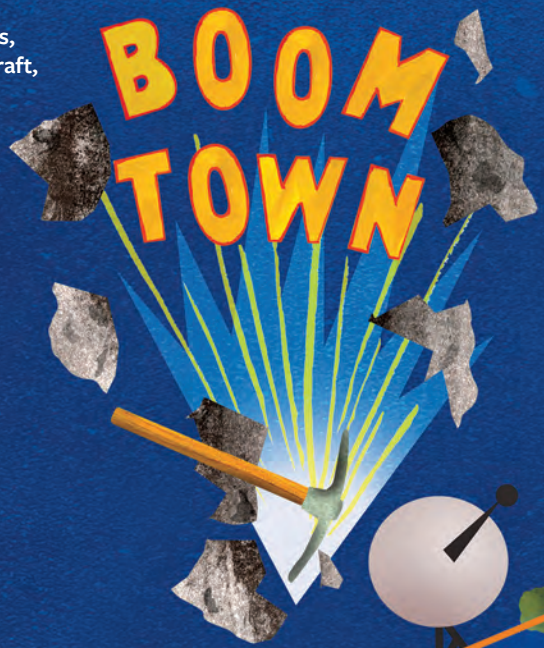
Adapted from Ramin Skiba's essay for *Nautilus* "Mining in Space Could Lead to Conflicts on Earth"



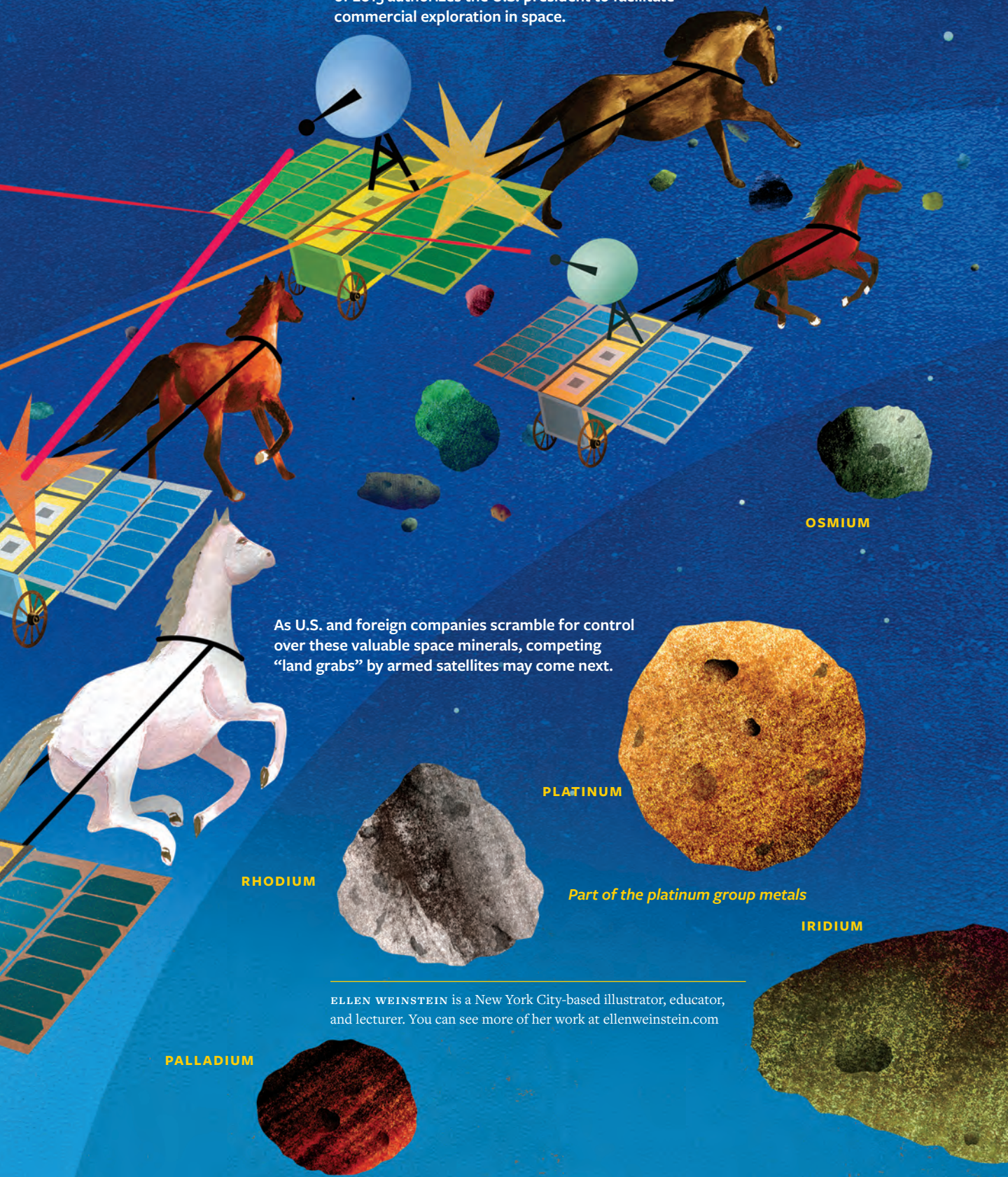
Space-mining activities could break up asteroids, creating hazardous debris for satellites, spacecraft, and astronauts.



A single, giant asteroid could contain as much platinum-group metals as all reserves on Earth.



The 1979 Moon Agreement declared outer space to be the “common heritage of mankind,” yet the Space Act of 2015 authorizes the U.S. president to facilitate commercial exploration in space.



As U.S. and foreign companies scramble for control over these valuable space minerals, competing “land grabs” by armed satellites may come next.

PLATINUM

Part of the platinum group metals

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IRIDIUM

PALLADIUM

ELLEN WEINSTEIN is a New York City-based illustrator, educator, and lecturer. You can see more of her work at ellenweinstein.com

Her Second Act



*Why a pioneer in theoretical physics
walked away from it all*

BY SALLY DAVIES

PHOTOGRAPHY BY TOM JAMIESON
ART SPOTS BY PING ZHU



INSIDE THE SOUTH LONDON OFFICES of Doppel, a wearable technology start-up, sandwiched into a single room on a floor between a Swedish coffee shop and a wig-making studio, CEO and quantum physicist Fotini Markopoulou is debating the best way to describe an off-switch.

Markopoulou and her three co-founders have gathered in convivial discomfort around a cluttered formica table and lean-to blackboard. They're redesigning the features of their eponymous first device, which is due to be released in October. It's a kind of elegant watch that sits on the inside of your wrist and delivers a regular, vibrating pulse. By mimicking a heartbeat, the Doppel helps regulate a person's emotions and mental focus.



Swiveling in a chair, Markopoulou says she likes a “smothering” gesture—placing a palm over the face of the Doppel to turn it off—because it is intuitive and simple, and the term suggests the device is “alive.” “You could always murder it,” deadpans commercial director Jack Hooper. Head of technology Andreas Bilicki chimes in. “Why not ‘choke’ or ‘asphyxiate’?” The team throws around alternatives: “throttle”; “go to sleep, to sleep”; “turn your Doppel off, just like putting a blanket over a parrot’s cage.”

Markopoulou, 45, observes the banter with a half-smile. She is fine-featured and striking. Her heavy-lidded eyes anchor a gaze that seems wary of its own powers, as if her promiscuous intelligence must hold itself back from latching on to your every word. She wears her hair in a tousled pixie-cut, and on this spring day, a green knit sweater and blue scarf with a pattern of fish-like scales. There are no airs about her, nor any indication that she’s 20 years older than the rest of the team. Markopoulou lives in Oxford but sleeps on design director Nell Bennett’s couch whenever she comes down to London.

After the meeting, Markopoulou and I walk downstairs to get a coffee. With the zeal of the reborn, she tells me how much she relishes the pleasures of making a product that people will use and pay for. “There is a very practical satisfaction to getting stuff done, whether it’s making something or selling something,” she says. “I do enjoy solving practical problems, like how to convince people Doppel’s a good idea, or how to get the right deal from an accountant.”

It’s hard to see how these tasks could fully absorb Markopoulou. She is one of the most radical and fiercely creative theoretical physicists alive today, and a founding faculty member of the Perimeter Institute for Theoretical Physics in Waterloo, Canada, where she was at the vanguard of quantum gravity. This is the branch of physics striving to unify the two most fundamental theories of the universe: general relativity, proposed by

“Removing the person is the whole point of training as a scientist.”

A NEW BEAT Fotini Markopoulou at work at Doppel, the wearable technology startup she co-founded, after saying goodbye to theoretical physics.



Einstein, and quantum mechanics.

Quantum theory describes the rowdy interactions of fundamental particles that govern many of the forces in the known universe—except gravity. Gravity is rendered beautifully predictable by general relativity, which envisions it as an effect of how the four dimensions of space and time curve in response to matter, like a piece of tarpaulin bending under a bowling ball. Quantum theory's ability to predict the behavior of an electron in a magnetic field has been described as the most precisely tested phenomenon in the history of science. But putting it together with gravity has so far produced absurd mathematical results. It's as if a soccer player and a tennis player were managing to carry on a game despite being ignorant of the opponent's rules.

After years of single-minded study, Markopoulou co-created a novel potential solution known as “quantum graphity.” This model of the universe operates at a scale that is tiny even by subatomic standards—as tiny in relation to a speck of dust as a speck of dust is to the entire universe. It suggests that space itself and its attendant laws and features could evolve out of interconnected dots to create the dimensions we experience as space, like a soufflé rising from a pan.

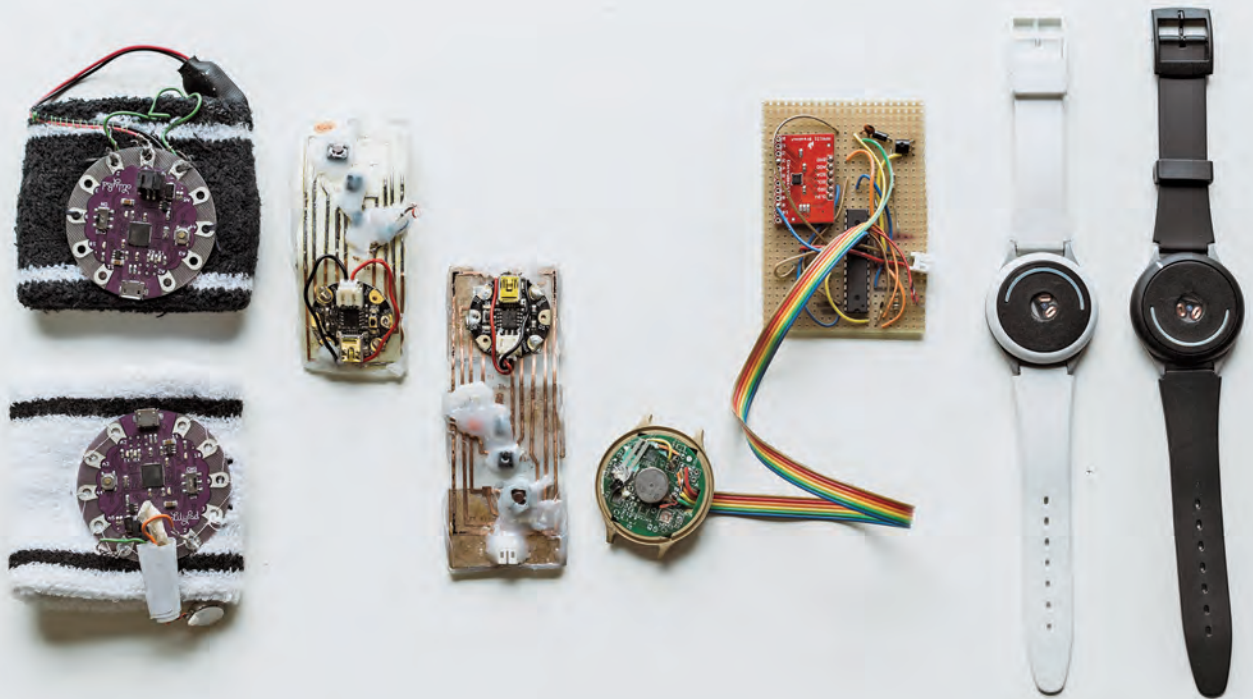
“Fotini is extremely original, original to a fault,” says Lee Smolin, a fellow founder of Perimeter who used to be married to Markopoulou. “Most scientists pick up on ideas which are dominant, which come from living figures, and develop them incrementally. She doesn't do that—she works solely on her own ideas.”

Between sips of a latte, Markopoulou describes how theoretical physics consumed her. “It's a lot like being in a monastery, like no normal human needs should make you waver from the cause of understanding where the universe came from,” she says. “In my previous eyes, just leaving is a moral failure, more than anything else. It's a devotion thing—your devotion has just gone.” She pauses to shape her next thought. “It's also not really a loss of faith; I changed.”

Five years after walking away from physics, Markopoulou is still trying to explain that change to herself. She was forced to re-examine her position when Perimeter's new director, Neil Turok, who joined in 2008, deemed her work too speculative and squeezed her out of the Institute. But her unease had deeper roots.

Working in a field where the air of reality was so thin, Markopoulou started to lose touch with her own life. “I have so many friends in their late 40s, and they still don't have an actual home or a family or anything. As long as they have a place where they can go and think they're happy.” She casts a wry smile. “I failed that test, obviously. For a lot of people that makes sense, and even for me that makes sense 80 percent. It's that other 20 percent that causes problems.”

Doppel embodies many of the qualities that Markopoulou came to miss in her work as a physicist. The company is grounded in psychophysiology, a field which considers the mind to be deeply rooted in the body and its



GET RHYTHM With a reference letter from her friend Brian Eno, Markopoulou enrolled in a program called Innovation Design Engineering at the Royal College of Arts in London, where she met her fellow Doppel co-founders. The fruits of their labor, a device that sends a mood-enhancing pulse to a wearer's wrist, is pictured above, from prototype to product. The team often made design and engineering notes on Post-its (p.31).

environment. But embracing the fact that the self is interwoven with the world, and at its mercy, is a frightening thought, Markopoulou says. Escaping that fear, and trying to pin down the interconnection between humans and the natural systems that make us what we are, is what drew her to physics in the first place.

“I did appreciate, for a long time, the way science detaches you from that scariness, because you ignore it,” Markopoulou says. “Between the truth of the physical world and a physics theory, there’s humans. Of course, nothing happens there, because removing the person is the whole point of training as a scientist.” A pause. “But this may or may not be possible.”



AS A TEENAGER GROWING UP in Athens, Greece, Markopoulou looked like an ordinary kid: permed hair, heavy ribbed sweaters, a penchant for Clint Eastwood Westerns. But she was already attracted to the study of transcendent truths. On her way home from school, she would sometimes drop in at Greek orthodox churches to lie on her back in the pews, and contemplate the elaborate scenes of stars and angels painted into the interior domes. One summer, when she was 15, she happened across a book in the library of the British Council with the title *Starseekers*, a quasi-mystical account of the history of cosmology, by English writer Colin Wilson. “I got totally obsessed with that book,” Markopoulou says. She convinced her mother, Maria, to buy her an Atari computer, and spent hours trying to translate *Starseekers* into Greek on a word processor.

Markopoulou lived with her mother in a cramped two-story studio in Athens, where Maria worked as a figurative sculptor. She was a magnetic, troubled figure, unafraid to set her own moral compass but riven with internal conflicts. She’d fallen pregnant one summer to a Greek sculptor she had known in Florence, where she trained as an artist against the wishes of her parents, and decided to raise the baby as a single mother in Athens. She was 33. “Her lovely way of putting this was, ‘Jesus was also 33 when he was put on the cross,’” Markopoulou says. “But it was also very clear that I was the best thing that had ever happened to her.” (Markopoulou has never met and knows little about her father, who died in 1997.)

Markopoulou loved accompanying Maria to exhibitions and openings, but struggled to disentangle her sense of self from her mother’s strong and particular judgments. “My mother’s relation with reality, it would be

wrong to say that it wasn't solid, but it was just different," Markopoulou says. Maria hated to sleep and refused to have a bed: "My mother clearly thought that sleeping was like dying, and that she might not wake up if she did, and something like a bed might as well have been a tombstone. I did realize as I was growing up that you couldn't rely on her description of something."

The subjectivity of aesthetic merit troubled Markopoulou. "One of the things I hated about the art-world is that decision-making is quite arbitrary," she says. "People could say Picasso is shit just because they felt like saying it. I found that very frustrating, and very political; they're gatekeepers, and then your life and self-perception is a function of those gatekeepers."

Markopoulou's education in Greece was "a complete disaster," she says, with teachers whose instruction consisted of reading the newspaper at the front of the classroom. In her final year of high school, Markopoulou went in search of private evening classes; by mistake, she walked through the door of an institution that offered A-levels, the exams for students entering the British university system. She hadn't considered studying in the United Kingdom, but ended up enrolling. "The usual story about people in quantum gravity is, 'I read about Einstein when I was 8,'" she says. That was not her. The pendulum for her imaginary career had swung between being an astronaut and an archeologist. She only selected theoretical physics under the pressure of her university application, and chose the course on the casual advice of a tutor at the school, a former NASA scientist, who said it would be a good balance for her aptitude in physics and mathematics.

Markopoulou failed her A-levels—"the first time I walked into the lab was for the exam, and half the questions I answered in Greek"—but, as part of the clearing process between teachers and universities, her tutor secured her a place at Queen Mary's University in London, her first choice. The department had several excellent particle physicists investigating the top quark, but the place retained the welcoming atmosphere of institutions unburdened by hallowed reputations.

Money was tight, so Markopoulou didn't have much of a social life. She planned birthday parties at McDonald's for a bit of extra cash, while her mother, who was living with her in London to get the rent from her studio in Athens, repaired antiques. (They would continue to live together until the last year of Markopoulou's Ph.D.) But Markopoulou loved it all the same. She and a clutch of the other undergraduates would relax in the

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chapel café between lectures, and occasionally head out in the evenings to hear one of their professors play amateur hard rock. At the same time, in her classes, she got wind of the fact that “there was some forbidden place”—that when it came to certain subjects, such as why time moves in one direction, it was better not to ask. She was not content with what the rules were; she wanted to know how they came to be.

TOWARD THE END of her undergraduate degree, a friend suggested Markopoulou attend a lecture on quantum gravity by Chris Isham, a rigorously mathematical physicist at Imperial College. He was also a Jungian analyst and devout Christian, with the air of a mystic and a fondness for peppering his lectures with passages from T.S. Eliot and Heidegger. “You can’t take out of the world the fact we see it,” Isham tells me. “What is the reality we hang onto? Well, it’s us, but who are we that sit inside this space which is relative to us?”

Isham was the first person Markopoulou encountered who could relate the technical dimensions of science to humans’ wider search for meaning. “Sometimes doing physics can be a bit like doing plumbing—you have your equations and tools and you go around and fix stuff, and if you do it in a smart way, people respect you,” she says. “Because you are a professional physicist, you get used to the idea that there are difficult questions that you do not do for a living. But these are what drove most of us to join the ranks.”

Markopoulou was developing her own clear vision of what she wanted to achieve as a physicist. “I am not going to devote my life to something because it’s beautiful—it’s this quest for the truth,” she says. “Science is not philosophy—there is not a lot of value in thinking about questions if you cannot come up with answers. But I’ve always been attracted to what is the furthest away you can get such that you can still come back with an answer. You’re trying to find the end of the coil to unfold it.”

Under Isham’s influence, Markopoulou started to grapple with quantum gravity. Her assigned Ph.D. project was based on a previous paper that examined the movement of dust particles to develop a new approach to splitting time away from the three dimensions of space. This sounds like a solution in search of a problem—surely time is a different thing from space?—until you remember Einstein’s counterintuitive insight that time is intimately interwoven with the fabric of space, and can be similarly twisted and bent by matter and movement. Time is dynamic, and defined by its relationship to what’s happening around it. It follows that there is no absolute time that the whole universe obeys—and more troublingly, when you push the equations far enough, time has a tendency to disappear entirely. “The relativity view of the world is that space and time is out there and it’s more or less a static thing—time is just another dimension,” the distinguished physicist Roger Penrose explains to me.

However, Einstein’s account of time doesn’t make sense in quantum theory. The quantum realm is host to all sorts of phenomena—particles existing in two places at once, or becoming entangled, as if they’re able

to communicate their properties instantly and seemingly telepathically, whether separated by a lab-bench or a light-year. It adopts a version of time that's far more conventional, like a metronome ticking away in the background, distinct from the bizarre behavior of quantum theory's zoo of quarks, bosons, and fermions.

It began to dawn on Markopoulou that you might be able to reconcile these two accounts of time by looking more closely at how they viewed space. After her first paper on dust modeling, she turned to spin networks. These are geometric models which help physicists describe quantum interactions in space, and fit more readily with the mathematics of general relativity. Markopoulou had the idea of combining spin networks with a "causal set," which allows time to be captured as a history of discrete events rather than a continuous flow. Showing how histories could be represented spatially let her bring a more substantive version of time into general relativity—one that wasn't rigid (as in some accounts of quantum theory) nor completely flexible (as in general relativistic spacetime).

Her work caught the eye of Smolin, an American theoretical physicist who at the time was visiting Imperial from Penn State University. He'd made a name for himself as a joint inventor of loop quantum gravity theory—a competitor to string theory in the quantum gravity sweepstakes—which was building on spin networks to develop a more sophisticated picture of quantum spacetime. Smolin helped Markopoulou shape her paper



on causal sets, and invited her back to Penn State for three months while she was finishing her dissertation. Shortly afterward, they married.

At the time, Penn State was a premier institution for non-string quantum gravity, and Markopoulou was surrounded by a number of other brilliant young scientists. “A bunch of different ideas were coming together; there was this sense that you might actually do something faster than the person in the next room, which is very unusual in quantum gravity,” she says. String theory had never appealed to Markopoulou, who saw it as cut-throat and conformist. “String theory has a very strong pecking order,” she says. “It comes with a strong machismo: What complicated stuff can you do? They’re very good at maintaining that.”

Some of Markopoulou’s contemporaries saw the equations pointing to the conclusion that time is an illusion at the fundamental level, and that what we experience as the progression of events emerges as a byproduct of fluctuations in space. But Markopoulou tended to attack the problem from the other direction—looking at time as the most important thing, and space as something that grows out of it, or is left as a trace, like a logbook of what has taken place in time. “I’m a bit extreme in that I would actually like to keep a fairly old-style time,” Markopoulou says. “I’m not wrong in my views. They come with challenges, but they also come with opportunities.”

“What is this reality we hang onto? It’s us. But who are we?”

IN EARLY 2000, WHISPERS went around the theoretical physics community that somebody wanted to donate \$100 million for an institute dedicated to foundational physics. Markopoulou and Smolin were approached by Howard Burton, a Canadian with a Ph.D. in theoretical physics from the University of Waterloo, who was the emissary for this Gatsby-like figure. “I genuinely thought the guy was a sociologist studying the reactions of physicists to that statement—the amount of money is crazy for foundational physics,” Markopoulou says. By now she was doing a postdoctoral fellowship at the Max Planck Institute for Gravitational Physics in Berlin. She and Smolin were flown in secrecy to Canada and only informed that the donor was Mike Lazaridis, the founder of BlackBerry, on the drive from the airport: “We spent the night at Mike’s house, where he made us french toast and talked us into coming to Waterloo.”

By the time Perimeter was set up, she and Smolin had separated, but

remained friends—which was just as well. To lay the scientific groundwork for the institute, the three founding faculty huddled together in a former restaurant, along with several postdoctoral students and Burton, whom Lazaridis had appointed as the director. They inherited the coffee machine and learned to make top-notch barista cappuccinos. The institute aspired to a flat management structure hospitable to free-thinkers, without tenured jobs or the ordinary hierarchies of a university physics department, in the hope that this would foster more interesting research.

While Markopoulou was not a forceful leader, she was a persuasive one, says Seth Lloyd, a physicist and professor at the Massachusetts Institute of Technology, and a longtime collaborator of Markopoulou's. He recalls trekking with her and some postdocs in the Sangre de Cristo Mountains, when she was on a fellowship at the Santa Fe Institute in New Mexico. "At each stage of the hike, there were different suggestions about where to go, and we always ended up doing what Fotini thought was a good thing," he says. "We had a great time, none of us ever thought Fotini was imposing her will—just that what Fotini seemed to want to do was the right thing to do."

At Perimeter, Markopoulou was at her best when the learning and experimentation were the quickest. Invariably her work became playful and synthetic. "At some point I thought we should just reduce the whole thing to the basic property of space, which is here and there," she says. Physicists were willing to toy with the nature of time and "hack" general relativity to create a quantum gravity theory, she says. But they seldom played with the nature of space or "hacked" quantum theory. With Simone Severini, an Italian computer scientist, and graduate student Tomasz Konopka, Markopoulou drew on quantum information theory to develop the notion of quantum graphity. "Fotini thought it was fun—this cute idea, that the universe is a big network, like the London Underground, that changes over time," Severini says.

Markopoulou was partly inspired by the principle of emergence, where complexity can emerge from simplicity, or, more to her point, simplicity from complexity, such as wiggling water molecules forming ice crystals or waves. Paramount in her model was the ability to create images that explained "geometrogenesis," her and her colleagues' term for the emergence of the structure of spacetime during a critical phase in the birth of the universe. "Once it starts being hard to visualize, I'm not happy, I get uncomfortable," she says. "I also think you can have an extreme richness while staying with very few building blocks."

She was tickled by an aperçu from Ludwig Boltzmann, the 19th-century Austrian physicist, who looked at the physical properties of atoms and said, "Every Tom, Dick, and Harry felt himself called upon to devise his own special combination of atoms and vortices, and fancied in having done so that he had pried out the ultimate secrets of the Creator." Markopoulou chuckles. "It felt to me, when we were arguing 'Is it my model? Is it your model?' we were totally every Tom, Dick, and Harry."



In quantum graphity, space evolves out of dots that are either “on” or “off”—connected or disconnected to the next dot. It doesn’t matter exactly what the dots are; they represent coordinates in a network of relationships, the fundamental constituents of the universe. The idea, Markopoulou explains, comes from a branch of mathematics known as category theory, in which “what something is, is the sum of how it behaves, rather than how it is.” At the highest possible energy, at the beginning of the universe, all the dots in the graph are joined, and no notion of space exists. But as the system cools and loses energy, the points start detaching, which creates the dimensions and laws of space. In this model, space becomes like



IN HER ELEMENT At the Perimeter Institute for Theoretical Physics, where she was a founding member, Markopoulou, seen here in 2002, was known as a persuasive, though not forceful, leader.

a crystal that forms out of a liquid as it cools. “The value of this is in trying to give, however primitive it might be, some language to talk about space not being there,” she says.

“It was very courageous of Fotini to start working on this,” says Sabine Hossenfelder, a research fellow at the Frankfurt Institute for Advanced Studies, a think tank devoted to theoretical physics, who from 2006 to 2009 did postdoc work at Perimeter. “It’s the kind of thing you think has been done long ago, but surprisingly it wasn’t.” It would have been much easier, Hossenfelder says, for Markopoulou to find a niche for herself within an existing theory, like loop quantum gravity. “But quantum graphity of course is much more exciting. It’s a new idea, one that could have done a good job bridging the gap between theory and experiment.”

As Markopoulou’s reputation grew, she was often called upon to represent Perimeter to the public. She was a young, accomplished woman in physics—a rarity. She enjoyed and tended to accept speaking invitations, partly to help change perceptions of female scientists. “For previous generations, the question was ‘Are there women in science?’ Now there are, but girls want to know, ‘Are they normal?’ When you seem to be happy, and you seem to be a woman they’d be happy to be, that’s a fairly big thing.” Her world revolved around quantum gravity. Shortly after separating from Smolin, she had fallen into a relationship with a German postdoctoral fellow at the institute, Olaf Dreyer, whom she married after four years. They lived and breathed their discipline. “It’s nice to share these things with somebody closely,” she says.

But Markopoulou found her more radical theories were sometimes greeted with the sly criticism that they were “creative.” “The fact that you don’t look like the standard makes it hard for them; they will take longer to form judgments, which means you stay in the doubt area for longer,” she says. It was made worse by the pervasive attitude among physicists that you should gather your laurels by doing sensible calculations throughout your career, and only cook up new theories of quantum gravity in your old age.

Markopoulou refused to play that game, and a sense of discontent began to build. Every problem she solved created a quagmire of fresh ones; and, daughter of sculptors, she was tiring of academic papers as the only tangible thing she could “make.” After a while, even her public-facing activities began to grate. “There is a part of me that felt like a kind of clown, telling people magical things about the universe,” she says. “Something you take very seriously and you’ve devoted your life to, and you’ve made your own sacrifices for, is, for other people, at best entertainment.” She consoled herself with something Isham once told her, counsel he’d received in turn from the physicist John Archibald Wheeler. When it comes to quantum gravity, he says, you’re bound to fail. “What’s important is not the fact you fail, but how you fail.” Markopoulou was determined to fail better, to borrow Samuel Beckett’s phrase.

In 2008, the South African physicist Turok was appointed director of Perimeter. Turok, who describes himself as “very demanding,” pulled back

from the more outré flavors of foundational physics and expanded into other areas, including particle physics, cosmology, and quantum computing. He didn't want the institute, he says, "to be center for alternative physicists who were doing unusual things in speculative directions."

By 2009, Markopoulou's personal life was undergoing its own quantum transitions. At a conference in Waterloo about physics and the financial crisis, organized by Smolin, Markopoulou met systems theorist and physicist Doyne Farmer. The pair was instantly dazzled by one another, and within five days decided to upend their lives to be together. Markopoulou separated from Dreyer and Farmer from his wife. Not long after, she got pregnant on a road trip from San Francisco to Santa Fe in Farmer's 1967 Datsun convertible. Their son, Maris, was born in 2010; a year later, Markopoulou's mother Maria passed away.

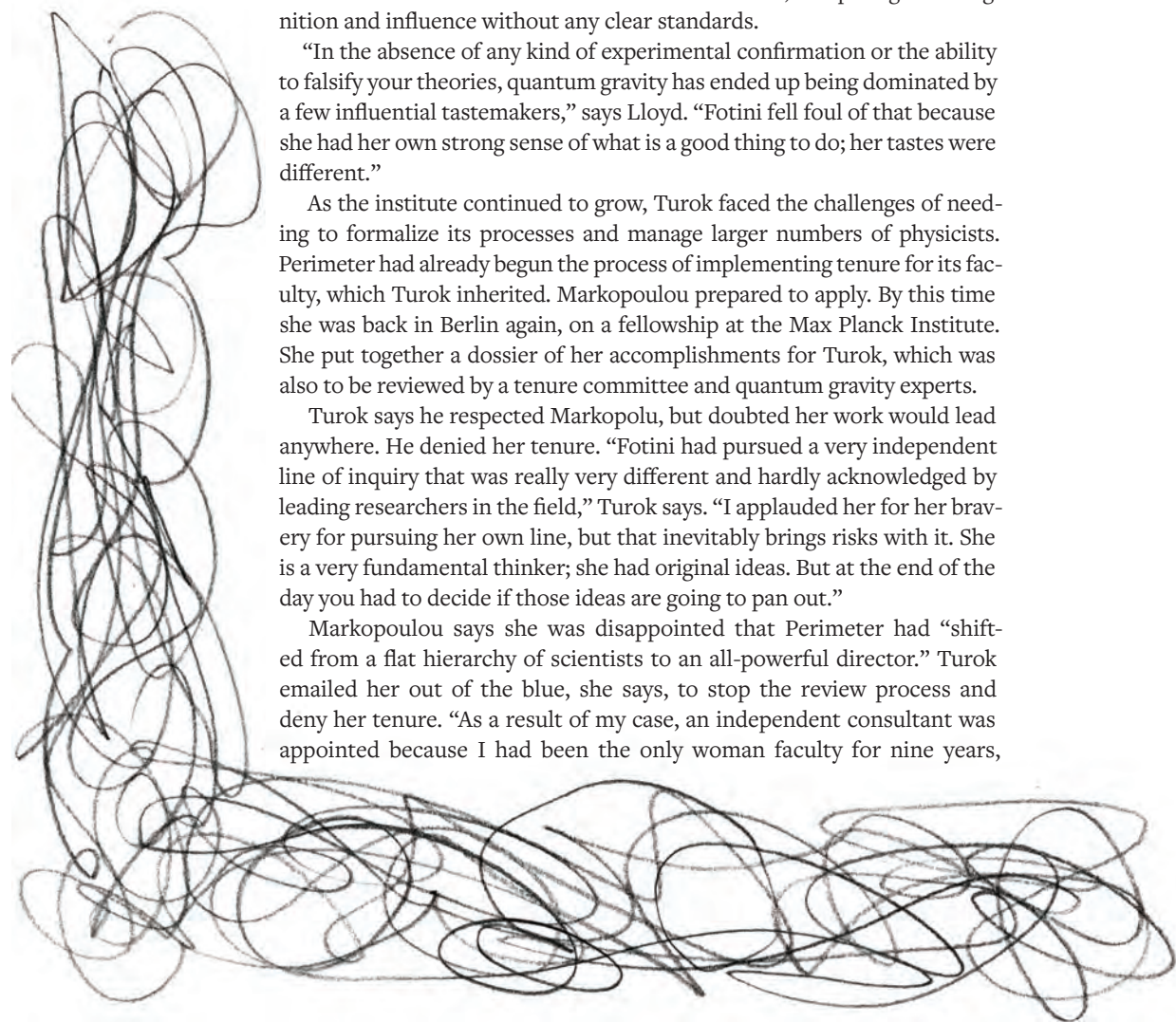
Markopoulou was still attracted to deep inquiry, but the further down she went, the less objective she found her colleagues' judgments about the value of her work. "If you're in a place where everything is certain, that's a very boring place," she says. "But if you jump out with no parachute, it's either a sociological exercise or a folly." She'd been striving to position her research at the metaphorical "edge of chaos," the point at which order emerges from complexity. But she'd started to get the creeping suspicion she was back with the artists in her mothers' studio, competing for recognition and influence without any clear standards.

"In the absence of any kind of experimental confirmation or the ability to falsify your theories, quantum gravity has ended up being dominated by a few influential tastemakers," says Lloyd. "Fotini fell foul of that because she had her own strong sense of what is a good thing to do; her tastes were different."

As the institute continued to grow, Turok faced the challenges of needing to formalize its processes and manage larger numbers of physicists. Perimeter had already begun the process of implementing tenure for its faculty, which Turok inherited. Markopoulou prepared to apply. By this time she was back in Berlin again, on a fellowship at the Max Planck Institute. She put together a dossier of her accomplishments for Turok, which was also to be reviewed by a tenure committee and quantum gravity experts.

Turok says he respected Markopolu, but doubted her work would lead anywhere. He denied her tenure. "Fotini had pursued a very independent line of inquiry that was really very different and hardly acknowledged by leading researchers in the field," Turok says. "I applauded her for her bravery for pursuing her own line, but that inevitably brings risks with it. She is a very fundamental thinker; she had original ideas. But at the end of the day you had to decide if those ideas are going to pan out."

Markopoulou says she was disappointed that Perimeter had "shifted from a flat hierarchy of scientists to an all-powerful director." Turok emailed her out of the blue, she says, to stop the review process and deny her tenure. "As a result of my case, an independent consultant was appointed because I had been the only woman faculty for nine years,



I had a strong academic record, and Neil stopped the tenure process just as I had a baby,” Markopoulou says. (“I respectfully beg to differ,” Turok responds. “A tenure review process was never initiated.”) The matter is subject to an out-of-court settlement.

In the autumn of 2011, Markopoulou walked out of Perimeter for good.

ONE SUNNY MORNING IN March, I visit Markopoulou at her home outside Oxford, perched on a hill and encircled by stands of oak, ash, and silvery birch. Nancy, the wife of the poet and classicist Robert Graves, used to run a grocery store on the site before the poet John Masefield knocked it down to build a theater in 1924. The top rooms sit snug under the original proscenium arch. Markopoulou loves theater—a legacy of being Greek, she says. It allows you to “step out of your normal shoes, to shift reality a bit, and to actively participate by forcing you to suspend your belief.” Not unlike science at its highest levels.

In the living room, Markopoulou bundles herself up into a burgundy armchair with the cheerful self-possession of a family cat. A Persian rug sprawls across the wood floor, monopolized by a Lego space station. One of her mother’s bronze busts broods from a windowsill, a beautiful, dauby figure of a woman with braids parted down the middle. “You were asking me the other day what made me change,” she says. “One big thing was my mother died and opened up a space for me.” Markopoulou wouldn’t have touched art while her mother was alive, but recognizes now that a similar desire to make, to craft and to create, is part of who she is.

“In many ways, physics and what I did are almost ideally positioned to my experience with my mother,” she says. “I probably did come out of that wanting a much more firm grasp of what is what, and objective decision-making. Now I don’t feel I need that much any more, but growing up that was a big deal. Also, it was far away from her, it was my own space, but at the same time there were many ways in which the deeper challenges are the same.” Sculpture is a lot like creating a physics theory, she says, because you have to turn it around and make sure it works from every angle. “You have to understand the essence of what you’re doing before

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“If I knew,
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you start, because only then do you have a chance that it's going to work from all sides."

Did she believe this philosophy could help her solve quantum gravity? "I never really wanted to single-handedly solve it. But I never went in thinking that we can't. I always assumed it was possible." Does she still think it is? "Not soon, but I don't know. If I knew, I would be doing it," she quips.

During her unsteady transition out of physics, Farmer was a pillar of support for Markopoulou. "I'm very much what I do, so going through a transition is a time when I don't know who I am," she says. "I was lucky to have the context where that was perfectly possible."

Farmer is a distinguished and idiosyncratic physicist in his own right. While still in grad school at the University of California, Santa Cruz, studying physical cosmology, he and fellow physicist, Norman Packard, created one of the world's first wearable computers. Released in the 1970s, it was a toe-operated device embedded in the tip of a shoe, which allowed the wearer and an accomplice to track the progress of a roulette ball and achieve a 20 percent advantage over the house. He and Packard later decided to found one of the first predictive stock trading companies, which was ultimately sold to UBS, a financial services company, in 2006. Farmer's interests now lie in "econophysics," a field which he founded and which applies the mathematics of natural systems to gather insights about the economy.

When Farmer landed a post at Oxford University in 2011, Markopoulou was faced with "the usual two body problem in academia" of trying to find a job nearby. But when she started looking, she realized her heart wasn't in it. She had been toying with industrial design, and asked the advice of the musician Brian Eno, a physics follower and a friend. He advised her to look into the master's program in Innovation Design Engineering run by the Royal College of Arts and Imperial College in London, and wrote her a letter of reference.

She sailed through the admissions process, which included an exercise where prospective students had to explain how they would evade a pack of zombies chasing them toward the lip of a cliff. She enjoyed the classwork but found the mental shift hard at first. "It just felt silly because you go from, 'This is how the universe started' to, 'This mattress has these bubbles.'"

But she loved making things, and also made the personal connections that evolved into Doppel. A sailing trip to Greece, in which the Doppel crew nearly scuppered Markopoulou's and Farmer's large-bottomed boat on the rocks off the island of Cephalonia, cemented the team's conviction that they could withstand the trials of doing a start-up.

The kernel for Doppel came from a piece in *New Scientist* about interoception—the way humans can discern the internal states of the body and conceive of it as "their own." The idea is that our sense of self is not merely a mental process that somehow envelops the body, but somehow arises from the two-way conversation between the brain and other organs. As Manos Tsakiris, the softly spoken psychologist and neuroscientist who

advises Doppel, tells me, “You cannot cut off cognition from the rest of the body, and you cannot cut off the body from the rest of the world in which you interact.” By harvesting your natural response to rhythm, Doppel runs counter to the notion that the self resides in the mind alone—that the human is a creature of the will, a maker of rational decisions, a sovereign mind bossing around dumb matter.

With hindsight, Markopoulou sees her work at Doppel as a “natural evolution” from what she did before. Isham had inspired her to pursue physics as a quest to understand reality from within, when scientists can’t stand apart from what they’re trying to analyze. But now, instead of the universe as the ultimate system, she has the human body. “If you think about physics, it’s a human creation. The equations represent stuff we come up with because of our senses. So shouldn’t our senses be part of what goes into physics?” Markopoulou says.

Markopoulou thinks that many disputes in science come down to competing metaphysical commitments. She recognizes that her own belief in the fundamental nature of time, and her dislike of timelessness, is a moral preference as much as anything else. “Most of the physics where time does not exist comes with determinism as well. There is something about thinking that time is real and being responsible for your actions,” she tells me.

This belief in the inexorable movement of time is what seems to have allowed Markopoulou to reinvent herself—to turn away from years spent building a career as a physicist and to start from scratch as a designer and entrepreneur. “This is the nice thing about me, but it’s also a little bit weird: When I do something, I just do it. So when I switched, I switched,” she says. “Our mind can live in the past, the future, or any fantasy place it wants, but our body only processes the now.”

Doppel is unlikely to be the end of Markopoulou’s journey. “Whatever it is that you do, it has to have a context. Academia is one context, business is another context. I can’t really tell you if it’s better or worse, it’s a different set of rules—and right now I have come to no conclusions as to what I think about those rules. I’m still exploring.” ☺

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THE ROBERT L. FORWARD novel *Dragon's Egg* begins with an intrepid graduate student refusing to accept that a noisy satellite signal is just a malfunction. It must have some meaning, she thinks—and it does, turning out to herald the passing by of an inhabited neutron star (and making graduate school look rather easy).

Even a malfunction, though, wouldn't really have been noise. We'd have to assume that some satellite engineer would be interested. In fact, it's hard to imagine any signal coming from space that would be of no interest to anyone. The noisiest signals are even sometimes the most important. Microwave and gravitational wave backgrounds, for example.

Our modern definition of noise, as unwanted sound or signal, is a relatively recent one. The word used to mean strife, and nausea. Is the new meaning a useful ontology? Or does it encourage us to dismiss what we can't interpret?

Welcome to "Noise."

—MS

"The silence, as they say, is deafening. Sitting in here, it's as if someone has turned the volume up inside of my head."

SUSIE NEILSON

"Noise Is a Drug and New York Is Full of Addicts" p.70

Noise

SOUND AND FURY



Running Is Always Blind

How your brain keeps you from falling on your face

BY SAM SCHRAMSKI

WEARING A HEADBAND of replica Tibetan prayer flags, Scott Jurek meets me in a park in Boulder, Colorado to demonstrate proper trail-running technique.

This isn't just jogging down a paved suburban street, but racing along forest and mountain trails that would tax even an unhurried hiker. Last year Jurek ran the entire length of the Appalachian Trail—2,189 miles in 46 days, the equivalent of nearly two marathons every day, over rocky terrain, up and down thousands of feet in elevation.

We walk along a dusty trail segment—while an avid trail runner, I figured I shouldn't embarrass myself by trying to keep up. What strikes me when I watch him running for demonstration purposes, though, is that Jurek never looks down, no matter how uneven the ground may be. He politely slows pace to stand still and shoot the breeze, waxing rhapsodic about stride rate and length. He calls upon his experience as a health practitioner—he was a physical therapist before he

went full-time as an ultrarunner—when discussing matters as complex as neuromechanics and as simple as exhaustion. But for all his knowledge, he isn't quite sure how he manages to jog these trails without twisting an ankle or falling flat on his face. “Well, you just do it,” he says. “You get in the rhythm, the flow. There's a lot to keep track of, but actually it's not all that complicated.”

But really, it is complicated. Most biomechanical studies deal with how we negotiate smooth surfaces, perhaps with changes in inclination. Even that is tricky. We are unstable creatures: Both walking and running are a continuous state of imbalance in which one leg supports our body while the other goes through a swinging motion. Somehow our bodies and brains tame the instability and make it productive. Textbooks commonly describe the process using a simple spring-mass model in which our legs are, as physiologist Daniel Ferris from the University of Michigan calls it, “a strikingly consistent set of pogo sticks” (see Pogo

Sticks on page 46). According to this model, running is essentially hopping on two legs. The rate is governed by just a couple of parameters, such as the speed and length of the leg.

The pogo-stick model captures the basic repetitive motion of walking and running, but it poses a puzzle. As the pioneering Russian neurophysiologist Nikolai Bernstein pointed out in the 1930s, the pogo stick moves in a very simple way because of its mechanical design, but the simplicity and fluidity of human movement cannot have such a straightforward explanation. Our muscles can act across our joints in a gargantuan number of ways: Their flexibility creates an enormous problem of control. Those seemingly infinite possibilities for motion, therefore, must be streamlined into a few routinized ones. How do our bodies and brains choose among all the possible courses of action, as if following an intricate trail map that offers multiple means of reaching a destination, and how do they do this in such a consistent way? And how are these choices made when the options expand greatly to include the myriad ways to sidestep a rock on a mountain trail? It seems like too much for the conscious brain to handle. As it turns out, it is.

IN 2008 YOUNG-HUI CHANG of the Georgia Institute of Technology started attaching springy exoskeletons to the feet of test subjects and watching them hop. Sometimes he wrapped participants in lead strips to simulate their full body weight; sometimes he asked them to hop into spaces marked on the floor, much like the Dance Dance Revolution arcade game. He observed that changes at one joint in our lower limbs are very quickly compensated for by changes in others. The body seems to minimize the control problem by making adjustments only when needed, often with minimal signaling. Ferris, meanwhile, has conducted research that shows something similar using treadmills that resemble jigsaw puzzles: Runners expend more energy on uneven surfaces than on level ones, but the difference is less than theory predicts. Evidently our hips, knees, and ankles become more efficient at moving when terrain becomes complex.

Birds do this too. They are model animals for studying locomotion: They are bipedal, have a human-like gait, and bound over uneven terrain with ease. Monica

Agility relies on cognition that occurs at a high level in the brain, but never breaks into conscious awareness.

Daley of the Royal Veterinary College in London keeps a flock of birds and adapted a treadmill for them to run on. She can substitute other materials for the surface of the treadmill, and she finds that the birds' legs adapt instantly when they touch the material. In one experiment, she used tissue paper that could barely support the weight even of a guineafowl, and yet even as they broke through the paper they recalibrated and ran on anyway, like Jesus walking on water. Other surfaces they tested included sand, foam, and gaping potholes.

The rapidity of their response to new situations intrigues Daley. Guineafowl legs are continuously making fine adjustments. In effect, they have tunable shock absorbers. On uneven surfaces, their legs go into a high-damping mode to reduce the shock of impact; on smooth surfaces, they shift to a low-damping mode to conserve energy. Daley explains: "The benefit of this is greater economy in smooth terrain (when shock absorbers are not engaged), and with the benefit of continued smooth motion in rough terrain (when the shock absorbers are engaged)."

The birds' response is mechanically mediated—that is, it happens instantly at the point their leg hits the ground, requiring no thought or anticipation at all. Scientists call it a "preflex" to distinguish it from a reflex, which, fast though it may be, still involves external control. The system works, in part, because the natural dynamics of the spring-mass model automatically stabilize the body against disturbances. The central nervous system simply isn't necessary. Daley points out that even the notorious Mike the Headless Chicken, the remarkable chicken from the 1940s that survived decapitation, could walk.

But such leg-level responses can explain only so much. They adjust for the quality of a surface, but can't in themselves lead us to evade rocks and roots. For that, we need the brain, which integrates multiple senses: proprioception (our internal bodily awareness), balance, and vision. In other experimental research Daley has conducted with birds ranging from pheasants to ostriches, she has shown that on uneven surfaces birds require neuromechanical feedback, most likely visual in origin, in order to make tradeoffs between stability and leg impact.

Although our brains help us trail run, it seems clear that our conscious self couldn't possibly keep up with each tree root and pebble. Interestingly, our visual system—and, with it, other sensory inputs—inform our movement in ways that bypass conscious awareness. “You have to understand that you have two or

more visual systems in your brain,” says neuroscientist Christof Koch of the Allen Institute for Brain Science. “One is vision-for-action and the other is vision-for-perceiving. We always get stuck on believing that what we think we don't consciously perceive isn't registered by our vision-for-action part of the brain.”

Those two systems are known, respectively, as the dorsal stream (which situates objects in the world and guides motion) and the ventral stream (which identifies what you are looking at and supports conscious awareness). In one demonstration of this divergence, psychologists asked people to grab a moving object and simultaneously utter “tah!” when they noticed its sudden evasion. On average, subjects' utterances occurred about 420 milliseconds after the fact. Parallel systems process the same visual information for grabbing and for speaking.

SURE-FOOTED SUCCESS Scott Jurek on the Appalachian Trail. Despite a deep knowledge of neuromechanics, he doesn't know how he runs without tripping over the many small obstacles on the paths. “You just do it,” he says.





Pogo Sticks

Virtually everyone in the field of biomechanics compares our legs to pogo sticks. Having not had the pleasure of riding one since I was a kid, and even then finding it inferior to burning ants with microscopes and the like, I decided it was my journalistic duty to track down the leading manufacturer of the oxymoronic adult pogo stick.

Vurtego, producer of the “highest performing pogo sticks in the world,” is run out of a workshop in a swanky office park in Orange County. Their products do not disappoint: Champion pogo professionals have used these devices to spring up to heights of 10 feet. Parents everywhere should be anguished after only a brief scan of videos involving this device. Vurtego’s V4, a leading model of the pneumatic pogo stick design, resembles a mix between an Arctic core sampler and a rocket-propelled grenade.

Depending on the hydraulic pressure, you can use the model for routine exercise or death-defying flips. Personally I was unable to gain more than a couple of inches off the slick blacktop of the office park with the V4, all the while being secured by Ian Britt, the company’s owner. Still, the sensation of jumping—hopping—seemed at once natural and entirely foreign. “Normally it feels very odd to use these for the first time,” Britt says, acknowledging that the motion isn’t developed in utero. “Most people have a real big learning curve on it.”

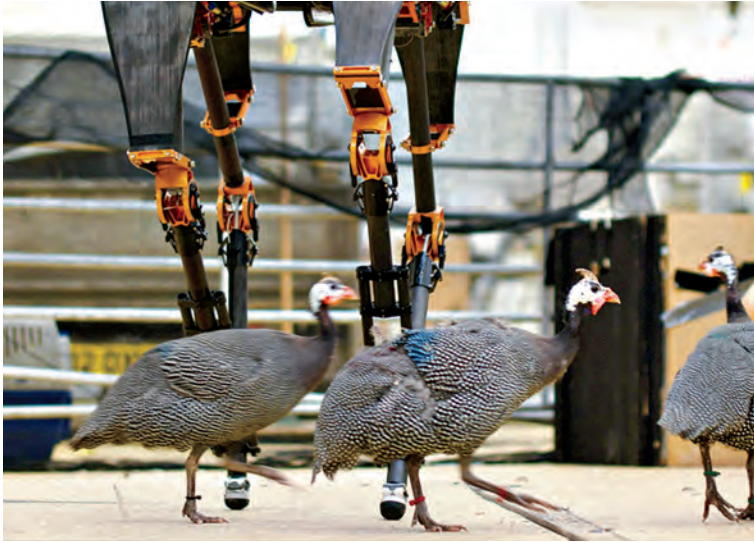
—Sam Schramski

In another interesting experiment, psychologists asked research subjects to look at a steep hill and estimate its slope. They gave their answer in one of several ways: Speaking, turning a dial to match the perceived angle, or tilting a board with their hand without looking at that hand. The first two estimates were conscious evaluations: The subjects took in the scene and sought to reproduce what they saw. The third involved a different pathway, from eye to hand, that did not entirely pass through conscious awareness. And the differences were telling. In their conscious estimates, people systematically overestimated the slope, but in their direct eye-to-hand estimates, they got it exactly right. When we decide to plan a motion—a conscious act—our brains often trick us, because geometric precision is less important than, say, the general physical difficulty of the climb. But when we go to execute the motion—unconsciously—we are exquisitely attuned to the environment.

So, when Jurek swears he doesn’t know how he manages to run on a trail, he really doesn’t. His agility relies on cognition that occurs at a high level in

Robots are still flummoxed by environments that humans maneuver without a second thought.

his brain, but never breaks into conscious awareness. That high-level functioning is impressive. Jonathan Matthis, a postdoc at the University of Texas, uses motion-capture suits to record the stride of a walking test subject, as well as eye-tracking cameras to precisely measure the subject’s gaze. The data show how they fix their eyes, relative to the phase of their gait. At the moment they actually take the step, they barely use visual information at all. “Walkers make extremely rapid and precise eye movements to gather the visual information they need about the upcoming terrain,” Matthis says, “while simultaneously placing the feet accurately on the basis of information gathered several steps in the past.”



BIRD WALK Guineafowl are model animals for studying human walking and running, and they have inspired robots such as ATRIAS (background).

To be sure, our brains do find other ways to integrate the available information. Jurek points out that a blind friend ran with him for part of the Appalachian Trail, and he marvels at his buddy's foot placement and finely tuned awareness. It's clear that the nature of our subconscious adaptation and response to noisy terrain is varied—and that all of us do it.

To get a glimpse of it myself, I went to the lab of James Finley at the University of Southern California. A full motion-capture suit, with all its sensors, can take two hours to put on, so I restricted myself to the head cap. Resembling a water polo cap, it monitors infrared light to measure blood oxygenation and volume, a technique called functional near-infrared spectroscopy, or fNIRS.

Finley uses the cap and suit to study how test subjects adapt to new situations. For instance, the good doctor asked me to walk on a treadmill in which the belt was split in two lengthwise to drive each leg independently. He moved the two belts at different speeds to try to throw me off balance, and it kind of worked. I stumbled clumsily. I continued to limp even when, unbeknownst to me, he had switched the belts to a single speed again. The reason, he explained, is that while I was walking with the belts moving at different speeds, my brain adapted its perception of speed to make me feel as though one was moving three times

faster than the other. Then, once the belts began moving at the same speed, my brain's prediction of their speeds was no longer accurate—I began to limp until my brain finally recalibrated. Never mind trail-running: Even walking is a minor miracle.

WHEN A ROBOT RUNS, it doesn't split the processing work between its conscious and subconscious self. It has neither. That doesn't mean that robots haven't taken great strides, in every sense of that term. But they are still flummoxed by environments that humans maneuver without a second thought, failing in many ways because they don't have the natural elegance to deal with complexity.

"The problem with robots is that they are very good at hopping and all kinds of other locomotion, but they find [running like] the spring-mass difficult, especially on uneven terrain," laments Hartmut Geyer, a locomotion researcher at Carnegie-Mellon who specializes in robotics. The Atlas robot from Boston Dynamics has recently demonstrated a remarkable ability to stay upright on icy pavement, but the company does not publish its control algorithms. Geyer speculates that they are based on an inverted pendulum, augmented by a flywheel to give the robot some extra maneuverability. The robot faces the same problem of stability as the human body, but, if Geyer is right, solves it in a



different way. That said, robots are like humans in that their control systems typically use a combination of simple, fast algorithms, in which sensory input directly affects movement, and slower algorithms that do general planning.

C. David Remy, a roboticist at the University of Michigan, has been particularly interested in the shifting that we undertake in our locomotion. Using robot simulations—and increasingly autonomous bots—he has found that the natural dynamics of human motion are in many ways defined by a frenetic starting and stopping, a switching of velocities that isn't unlike that of gears in any machine. Our changes in velocity look remarkably jagged—and similar to those of our metallic brethren. Our joints, muscles, and sinews soften the edges of our motion, but if our brains were controlling machine parts rather than organic tissue, our gait would be just as disjointed and jarring as C3PO's.

Perhaps one day we will design robots that move through a crowded house without getting caught on the rug or running over the cat. And, whether it's through

robotics or human studies, if we could understand how Jurek runs a trail, perhaps we could help people in every part of the movement spectrum, whether it's elderly people challenged by a walk down the hall, or even pro runners.

After Jurek does a demonstration run for me, deftly making his way down the rocky trail, he stops to wipe off a few dollops of sweat, likely from an earlier morning run, and confesses: "Your body can accomplish a lot, but at the end of the day—like those days where I'd be running for hours on the AT—sometimes you just start stumbling and giving in." 🌀

SAM SCHRAMSKI is a freelance journalist and researcher currently based in Bloomington, Indiana. He has yet to win a 100-miler but won't give up until robots start finishing ahead of him.

ADDITIONAL READING

- Birn-Jeffery, A.V., *et al* Don't break a leg: Running birds from quail to ostrich prioritize leg safety and economy on uneven terrain. *Journal of Experimental Biology* **217**, 3786-3796 (2014).
- Blickhan, R. The spring-mass model for running and hopping. *Journal of Biomechanics* **22**, 1217-1227 (1989).
- Castiello, U., Paulignan, Y., & Jeannerod, M. Temporal dissociation of motor responses and subjective awareness: A study in normal subjects. *Brain* **114**, 2639-2655 (1991).
- Chang, Y.H., Roiz, R.A., & Auyang, A.G. Intralimb compensation strategy depends on the nature of joint perturbation in human hopping. *Journal of Biomechanics* **41**, 1832-1839 (2008).
- Daley, M.A., Usherwood, J.R., Felix, G., & Biewener, A.A. Running over rough terrain: Guinea fowl maintain dynamic stability despite a large unexpected change in substrate height. *Journal of Experimental Biology* **209**, 171-187 (2006).
- Finley, J.M., Long, A., Bastian, A.J., & Torres-Oviedo, G. Spatial and temporal control contribute to step length asymmetry during split-belt adaptation and hemiparetic gait. *Neurorehabilitation and Neural Repair* **29**, 786-795 (2015).
- Grabowski, A.M., *et al*. Running-specific prostheses limit ground-force during sprinting. *Biology Letters* **6**, 201-204 (2010).
- Han, J., Waddington, G., Adams, R., Anson, J., & Liu, Y. Assessing proprioception: A critical review of methods. *Journal of Sport and Health Science* **5**, 80-90 (2016).
- Koch, C. & Crick, F. The zombie within. *Nature* **411**, 893 (2001).
- Matthis, J.S., Barton, S.L., & Fajen, B.R. The biomechanics of walking shape the use of visual information during locomotion over complex terrain. *Journal of Vision* **15**, 10 (2015).
- Proffitt, D.R., Bhalla, M., Gossweiler, R., & Midgett, J. Perceiving geographical slant. *Psychonomic Bulletin & Review* **2**, 409-428 (1995).
- Sugovic, M., Turk, P., & Witt, J.K. Perceived distance and obesity: It's what you weigh, not what you think." *Acta Psychologica* **165**, 1-8 (2016).
- Wiesmeier, I.K., Dalin, D., & Maurer, C. Elderly use proprioception rather than visual and vestibular cues for postural motor control. *Frontiers in Aging Neuroscience* **7** (2015). Retrieved from doi:10.3389/fnagi.2015.00097.
- Voloshina, A.S. & Ferris, D.P. Biomechanics and energetics of running on uneven terrain. *Journal of Experimental Biology* **218**, 711-719 (2015).
- Xi, W., Yesilevskiy, Y., & Remy, C.D. Selecting gaits for economical locomotion of legged robots. *The International Journal of Robotics Research* (2015). Retrieved from doi:10.1177/0278364915612572.



We Weren't Designed to Appreciate Good Perfume

Our sense of smell may have evolved to detect danger, not beauty

BY COURTNEY HUMPHRIES



EVERY DAY, WE INHABIT a vast and complex brew of odors. Take a walk in New York City, and you'll pass through aromas of car exhaust, garbage, coffee, baking pizza, flowers, damp soil, cleaning fluid, and urine—all in the space of a few blocks. At worst, the city reeks. At best, all of the scents blend together into something barely noticeable, with the occasional whiff of something delicious. We each live in a world of scents that go unnoticed in the backgrounds of our lives; they hum at the edges of our ability to perceive them. It can be a “big blur,” says Christophe Laudamiel, a French master perfumer who is based in New York and Berlin. It doesn't have to be. “If you are trained, if you are an expert, you can discern things in the noise that you don't discern if you haven't practiced before.”

When Laudamiel walks around New York City, he says, the city's many aromas don't just blend together into something inscrutable. He smells hints of wood and green bell peppers in a cup of coffee, tuna cans in a glass of bad cabernet, spinach in fine green teas at the market, and notes of freesia and mushrooms in

Central Park in the morning. “Once the brain has seen something, it can recognize it in other places,” he says.

That's a phenomenon I can attest to: As a perfume lover who has spent the past few years smelling hundreds of different fragrances, I can now identify and understand odors that would have barely registered before. It's led me to see perfumers—and the fragrances they create—as a window into learning about the olfactory system, our least understood sense. They show how our sense of smell is capable of much more than we typically ask of it.

LAUDAMIEL IS GETTING READY to launch his own line of perfumes. He has heavy competition: There were over 1,500 perfumes launched last year alone. But many of those perfumes, he argues, are just copies or remixes of other fragrances. “People think they don't know how to smell, because everything smells the same,” he says.

For his brand to be successful, he needs to cultivate an audience of aesthetes. “I know that if people are more educated, like with chocolate or whiskey, then



ILLUSTRATIONS BY HANNAH K. LEE

the industry becomes more interesting,” he says. When customers are motivated to distinguish smells from one another perfume makers will be obliged to offer more variety. But building a discerning audience for fragrance is challenging: It’s difficult to both create and perceive clear signals.

Our sense of smell is notoriously imprecise. Many people have a hard time recognizing and naming even basic odors. “The sense of smell is not built to identify things; it’s built to classify things,” says Johan Lundstrom, an olfactory psychologist at the Karolinska Institute in Sweden. “We’re quite good at saying ‘this is a flowery perfume.’ But going from there to saying ‘this is Chanel No. 5’ is really difficult.” Analyzing Chanel No. 5’s many ingredients is even harder, as is describing it with our very limited language for smells. But science also shows what perfumers know from experience: Our noses have an amazing ability to distinguish different smells—when we pay attention.

While the retina in your eye, for instance, uses a mere three types of cone cells (blue, green, and red) to detect the full range of colors, your nose needs a more complex system to detect different smells. There are an unknown number of odor molecules—chemicals

that escape into the air from their sources—that we are able to detect with smell receptors in the lining of our noses. Humans have about 400 different smell receptors, each of which may respond to several odors, while each odor molecule may bind to several receptors and activate the nerve cells carrying those receptors to different degrees.

Scientists still have no consistent way of predicting how a molecule will smell based on its structure, much less how a stew of odors will smell. This complexity makes composing a perfume more challenging than mixing colors of paint or layering musical notes.

Perfumers use a palette ranging from a few hundred up to 2,000 ingredients that range from a single molecule to natural oils that may contain dozens of odor molecules. “Each molecule comes with baggage,” says Laudamiel. “An apple-y note can smell of apple, but it can also smell of vomit.” A natural chemical called *cis-3-hexenol* smells of fresh cut grass, but at too high a dose can smell like a harsh solvent. Often when he adds one ingredient to a mix, Laudamiel must add something else to mask an unwanted effect. Each new ingredient alters the whole.

Perfumery is less a science than a storehouse of

You change one thing and then your whole fragrance collapses.





MASTER PERFUMER Christophe Laudamiel is preparing to launch his own line of perfumes, which will be called The Zoo.

knowledge and experience. Perfumers create iteratively, first adding ingredients and then “balancing” them (finessing the concentrations and masking unwanted odors). It’s like constructing a house of cards, Laudamiel says: “You change one thing and then your whole fragrance collapses.”

In the end, a perfume can contain 50 or more different ingredients at specific concentrations. And yet a perfume with 100 ingredients may not necessarily smell more complex than one with 10. Our olfactory system tends to combine mixtures of scents into a single odor. “If I’m inhaling a bunch of molecules at the same time, the olfactory system likes to put those molecules together into an object,” says Donald Wilson, a neuroscientist at the New York University School of Medicine. The ability to deconstruct an object into its component parts is an analytic process (for instance, you can visually analyze the shapes of each letter on a screen). Smell, on the other hand, is often considered to be synthetic; a scent is perceived as the sum of its parts. Since most odors are complex molecular mixtures, it makes sense that the brain would blend parts into a whole—it’s more important to smell an apple as an apple than as a cocktail of airborne chemicals.

Studies conducted in the 1990s asked people to identify odor molecules in random mixtures; many could distinguish the individual components of odor pairs, but as the mixtures became more complex, it was much harder to identify each one. There are exceptions: Some sulfur compounds, for instance, are so potent to our noses that they always pop out. But in general, after a smell reaches three or four components, its complexity dissolves into something indistinguishable.

That applies even to trained experts. “Even if the [perfume] formula has 50 ingredients, when I smell it right now, I’m going to see like four, five, six different things,” says Laudamiel. He might be able to pick out more ingredients as the fragrance changes over time and the most volatile molecules disappear. He can also infer ingredients knowing that a certain recipe creates an olfactory effect.

Ron Winnegrad, a perfumer and instructor at the International Flavors & Fragrances perfumery school in New York, says perfumery students spend their first months of training learning to identify and describe about 300 core ingredients, alone and in mixtures; eventually, they’re asked to deconstruct an entire

perfume by sniffing out a few ingredients at a time. And this ability requires maintenance. “I feel the perfumer should be practicing his whole career,” he says.

Most odors, from coffee to a rose to a perfume, are made up of tens to hundreds of different odor molecules, only some of which may get sucked into the nose in a particular sniff of the air. We make sense of this incomplete information through a process of pattern recognition, much like you can recognize a face in a grainy image. Pattern recognition helps perfumers: They might use rose oxide, a chemical found in roses, rather than expensive and more complex rose oil, because our noses still recognize the pattern of “rose.”

Categorizing and naming unfamiliar patterns, not to mention creating them, is harder. A 2012 study, led by Noam Sobel at the Weizmann Institute of Science in Israel, found that mixing many odors together can achieve something like white noise—they call it “olfactory white.” The study tests a fundamental aspect of smell: As odors are combined into large mixtures, do they tend to converge on a similar perception, or do they diverge into different smells? The answer can tell us something about how we make sense of increasingly complex inputs.

His team asked people to distinguish between mixtures of many odors that were carefully calibrated to have equal smell intensities and to span the different types of odors that humans can smell. They began with pairs of smells and built up to larger mixtures. Once they reached about 30 components, the mixtures began to smell the same. The researchers then created 40-component mixtures, which they labeled with the nonsense word “Laurax.” After smelling these mixtures, subjects tended to assign the name Laurax to other large mixtures with different ingredients. Although olfactory whites didn’t smell like any identifiable odor, a professional perfumer was asked to describe them, and came up

with words like cinnamon, vanilla, butter, and cherry candy; the test subjects also rated olfactory whites as generally pleasant and edible-smelling.

The study suggests that as more ingredients are blended, mixtures become more alike. Perfumes can have more than 30 or 40 ingredients, but they’re designed to highlight certain ingredients over others. A smell that’s equivalent to olfactory white can be found in the air in perfume labs, or in the discard bins where perfumers dump all the fragrances they’ve been working on when they’re finished. I once sniffed a bucket

like this at a perfume lab, and it smelled like everything and nothing in particular—vaguely fruity, like a disembodied strawberry.

But while the olfactory white mixtures in Sobel’s study were all classified as “Laurax,” that doesn’t mean they smelled exactly the same. We call lots of paint colors “white,” yet can tell the difference between slightly different shades. The same is true for smells. Though humans are bad at identifying and describing smells, we are much better at distinguishing one from another.

Leslie Vosshall, a neurobiologist at Rockefeller University in New York, has been playing around with shades of olfactory white in her laboratory. She describes these mixtures as “warm and beige and rounded,” and if pressed to make an association says they smell a bit like “Welch’s grape juice or wallpaper or garbage.” She’s interested in using them to find an olfactory “metamer,” two mixtures that smell indistinguishable even though they are made from different odors. In color vision, metamers can be created by mixing different colors together to achieve the same color. If the same trick can be done for smells, Vosshall says, it might reveal something about how olfactory receptors are activated by those smells and perceived by the brain. So far, though, it’s been difficult to find smell



“If I say there is leather and saffron, you are going to smell leather and saffron.”

mixtures that at least some people cannot tell apart. Vosshall suspects that if subjects in Sobel’s study were given different categories for Laurax (Laurax₁, Laurax₂, Laurax₃, and so on), they would be able to sort them.

IN STUDIES, MANY PEOPLE FAIL to identify even the most basic of household smells, like orange or coffee. The language available to describe more complex smells is limited. That makes it challenging to discuss perfume. “The big problem in perfumery is we don’t have any vocabulary,” says Laudamiel. “If I tell you ‘it’s apple-y, rosey vanilla,’ you have no idea what it smells like.” It could describe many different perfumes depending on proportions and other ingredients in the mix. And the marketing copy that accompanies a fragrance is often misleading, he says. They say “‘an orchid from Peru,’ [but] you smell it; there is no orchid from Peru in there.”

Laudamiel says he prefers to use ingredients that paint a vivid picture, and to use more transparent descriptions. “If I say there is leather and saffron, you are going to smell leather and saffron,” he says. One of his new fragrances highlights immortelle from Corsica, a flower that has a distinctive but hard-to-describe smell reminiscent of maple syrup, curry, and chamomile blossoms. Rather than bury it in a blur of other notes, he wants customers to perceive it clearly by using a high concentration of the key ingredient, so they’ll be able to remember and identify it later.

AS INEPT AS WE ARE at identifying smells, it’s rare for test subjects to smell an odor that they don’t find either pleasant or unpleasant. Many scientists believe that our sense of smell helps us navigate the chemical world

quickly; it’s about survival, not sophisticated aesthetic judgments. “My opinion is that the main purpose of the sense of smell is to paint with a broad brush,” says Lundstrom. “It’s first and foremost a warning sense.”

Lundstrom says that the olfactory system filters the world into things we want to approach or avoid. That’s evolutionarily important if we’re trying to avoid toxic substances and feed ourselves. “It’s always better to over-classify something as good or potentially bad than to be very accurate but very slow,” he says. Perfumers, for obvious reasons, prefer to make use of smells we already like to approach, like fruits and flowers, although repulsive smells like civet musk and indole (a natural molecule with a fecal odor) have traditionally been used in small amounts to add complexity to perfumes. Laudamiel says that perfumers are often told that customers decide whether they like a perfume or not within 10 seconds.

Olfaction is the only sense that feeds information directly to parts of the brain involved in memory, emotion, and body regulation without first passing through the thalamus, a region involved in consciousness that acts as an information filter. “We have this enormous amount of cortical processing that is happening in a non-conscious way,” says Lundstrom. So while a great deal of research on olfaction shows that smells have a powerful effect on us—stirring emotions and memories and even guiding our behaviors—these effects are not always accessible to our conscious thinking.

All of this can reduce the spectacularly complex world of smell to binary categories before we’re even aware of it. Vosshall says that many scientists regard it as “kind of a workaday sense; all we need to do is say ‘good/bad,’ ‘food/not food.’”

It’s a view she vehemently disagrees with. Her work on odor discrimination shows that at least some aspects of smell have a very high level of complexity. In 2014, Vosshall’s lab published a study based on their work with olfactory white mixtures, claiming that



humans may be able to distinguish more than 1 trillion odors. The paper was controversial; some researchers believe it wildly overestimates the number of discernible smells because the number was extrapolated from a limited set of experimental data. Whether the figure is true or not, it has raised discussion about how many different odors we can discriminate, and how our sense of smell is used.

“People can make fine discriminations,” Vosshall says. “I feel that people who pay attention to it, people who are trained, who care about it, absolutely are using it. And I think everybody else, in subtle ways that they don’t think about, must also be using it.”

Avery Gilbert, a smell psychologist who has conducted research for the fragrance industry, says that the key to human olfaction is flexibility. “It’s about extracting as much information as you need to solve your contextual problem at the moment,” he says. “Those decisions of ‘good or bad’ are being made in the first milliseconds.” In some situations, he speculates, that’s all we need. “By the time you get around to naming it, the tiger’s gotten you.”

But unlike a mouse, which is hardwired to flee from the smell of cat pee, he says, “humans are really super flexible, so we build cognitive structure when we need it.” In other words, we can use smell quickly to avoid danger, but when making finer distinctions is important to us, we’re capable of much more. Perfumers, for instance, use classification and language to aid their ability to recognize and imagine odors. Non-perfumers can do the same.

In fact, Laudamiel’s approach to perceiving scents is to harness both of these aspects of olfaction. He cites the science showing that pleasantness is an organizing principle around which we smell—Laudamiel calls it the “survival index.” At the same time, he says, “the nose is very, very good at smelling differences.”

His advice for olfactory novices is to put both of these qualities to work: “Compare, compare, and compare, and you will see a lot of things that your nose is telling you for your survival—to feed, to have sex, to alert you, or for psychological survival,” he says, “it is not all about survival or pleasantness: Certain smells also ‘grow on you,’ just like a food or a piece of art which at first was not liked.” Compare the aromas of two perfumes, two cups of coffee, or two potential

romantic partners, and you’ll begin to discern and remember the distinct smells that characterize the ones you prefer and the ones you don’t.

“In any event,” he says, “no more bullshit: ‘I cannot smell,’ ‘I’m not an expert,’ and the like. Smell, smell, smell—your food, your partner, or your partners-to-be, your animals, the air.” Your nose will be smarter for it. ☺

COURTNEY HUMPHRIES is a freelance journalist in Boston who writes about science, health, nature, and the built environment.



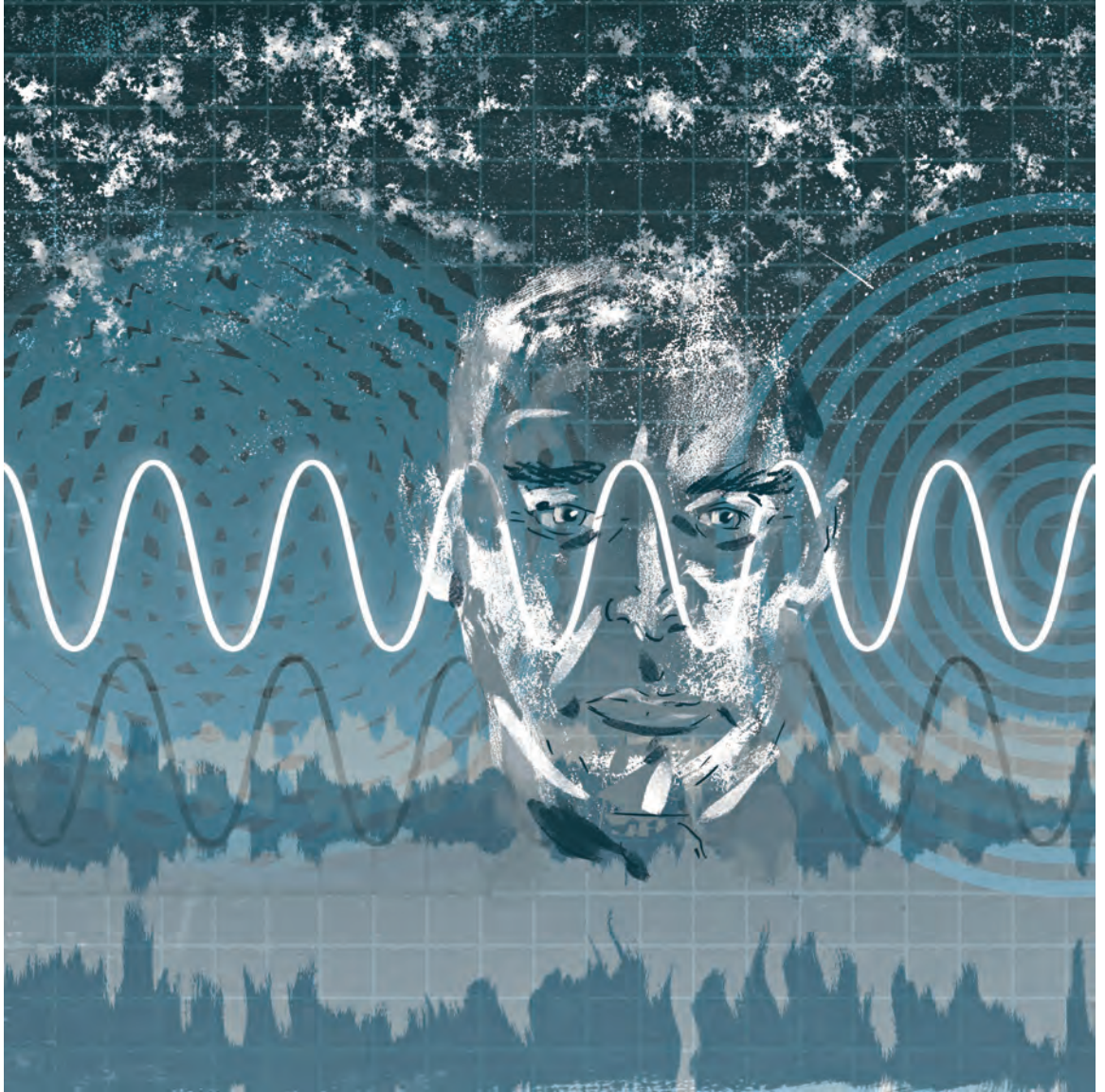


ILLUSTRATION BY **RIC CARRASQUILLO**

These Nature Photographs Aren't What They Seem

The visual playfulness
of Simen Johan

BY REBECCA HORNE
CAPTIONS BY SIMEN JOHAN





SIMEN JOHAN'S PHOTOGRAPHIC SERIES reads like an off-kilter field guide. Giraffes lose their heads in the fog, louche primates debauch with domestic animals, and tapestry-like camouflage both conceals and dazzles. Climate, habitat, and species are fragmented and remixed. To create the vivid images in his long-running series, "Until the Kingdom Comes," Johan uses a grab bag of techniques and effects.

The near-life-sized images show animals in diverse locations: nature preserves, zoos, and dioramas at natural-history museums. Some take years to complete, involving intricate set building and post-production work. Others are mashups of multiple images of animals in various habitats, locations, and seasons. A few are simply straight photographs. It can be hard to know exactly what you are looking at, and that is just as the artist wants it.

There is a certain amount of visual problem-solving required to decipher these puzzling images. In the 1999 paper "The Science of Art," neuroscientist V.S. Ramachandran and philosopher William Hirstein wrote that understanding images involves perceptual grouping, to discriminate figures from backgrounds, and that this experience can be inherently satisfying to the human mind. Our eyes are also drawn to high-contrast parts of images, which tend to be information rich. Camouflage in nature works partly by taking advantage of these predictable processes. In "Until the Kingdom Comes," camouflage is also used to trick us in a deeper way, confusing the plains with the jungle, one country with another, the real with the fake.

Johan suggests that his artistic impulse to cultivate uncertainty has its roots in his own life-changing experiences, including a snowboarding accident that left him in a coma for a short time. "Reality has this false sense of certitude that's easy to take for granted, and I used to be heavily invested in it—my identity, goals,

and whatever else—until certain events triggered me to see through the illusion," he says. "There was a collapse in perceived meaning and purpose that haunted me for some time, but ultimately brought me deeper and helped me get a better sense of myself and the world."

Through his work, the artist seeks to share a similar sense of destabilization with viewers, a reminder of the tenuousness of reality. The heightened, almost surgical precision of Johan's images can both create and dispel illusions. His creatures may tease the eye, but the disorienting experience can lead to insight.

Johan's work specifically raises questions about the distinction between the natural and artificial. The photos can at first glance seem like straightforward wildlife photography, but a closer look reveals the hand of the artist throughout. Yet if humans are animals, can we, or our art, be regarded as something divorced from nature? "If we saw ourselves as part of nature, not separate from it, that would increase our sense of responsibility," Johan says. Likewise, we are subject to the same forces as the rest of the natural world. "There's a code built into life to constantly improve upon itself; you see it both on a micro and on a macro level," Johan says. "If humans fail, something else will take over." 🌀

REBECCA HORNE is a California-born, Brooklyn-based artist, writer, and multimedia producer.







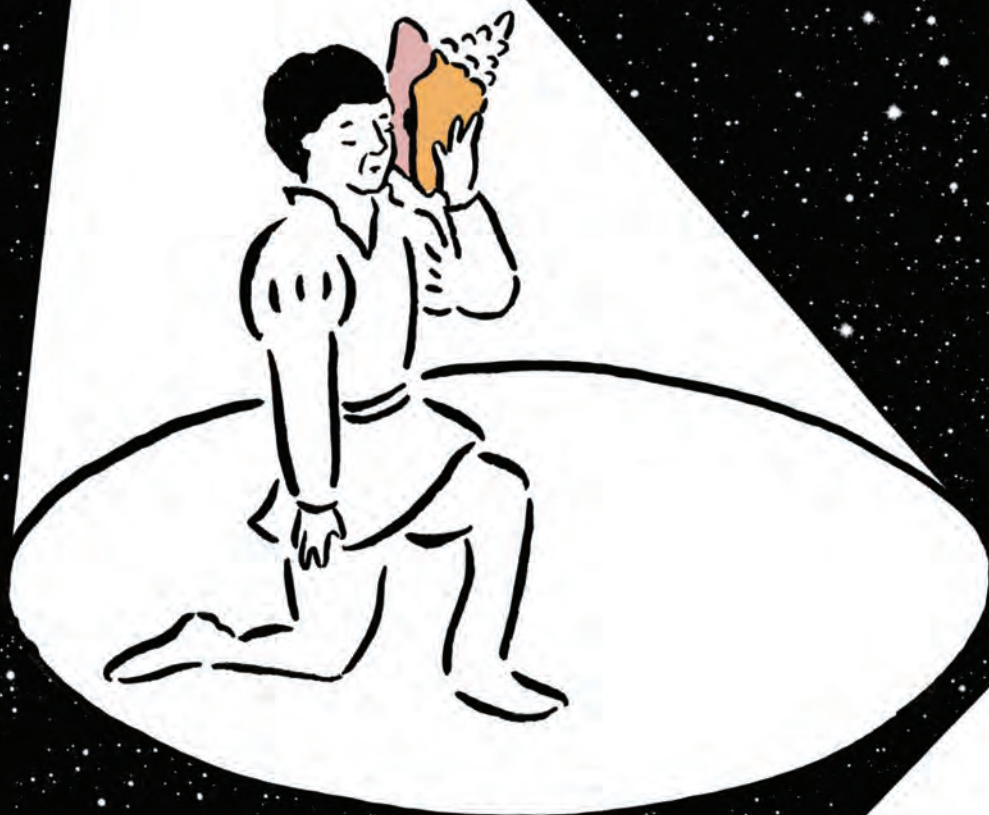
Simen Johan describes his photos:

OPPOSITE PAGE The giraffes were photographed at different zoos; the background mixes Iceland with Turkey. It just made sense to stick their heads in the clouds. Photography speaks the language of natural vision. It is the closest thing to reality, except for film.

ABOVE Indonesian peacocks in a Spanish pepper tree. The leaves of the tree mimic the birds' feathers. Camouflage is nature's way of confusing the things we see. Our perceptions are clouded by our desires, fears, memory, senses, culture, media, and more. We tend to look to nature for authenticity, but even here we encounter illusion.

PAGE 58 The zebras are in a zoo; the foliage is from Florida and Bali. I like the artificial logic: The zebras are camouflaged by incongruent foliage, as if that's why they're striped. In reality they're striped to confuse predators on the plains. Reality is logical like that, until questioned.

PAGE 61 The flamingos live in Virginia, and I'm not sure where I got that background. I photograph most of my material candidly because when you're dealing with animals and nature, you're only going to get what you're going to get. Animals never look how you expect them to look or do what you want them to do.



THE SEA
OR NOT
THE SEA?



The Noise at the Bottom of the Universe

The origin of quantum noise is the modern incarnation of a millennia-old debate

BY GEORGE MUSSER

TO A PHYSICIST, PERFECT QUIET is the ultimate noise. Silence your cellphone, still your thoughts, and muffle every kind of vibration, and you would still be left with quantum noise. It represents an indeterminacy deep within nature, bursts of static and inexplicable motions that cannot be gotten rid of, or made sense of. It seems devoid of meaning.

Considering how pervasive this noise is, you might presume that physicists would have a good explanation for it. But it remains one of the great unsolved problems in science. Quantum theory is silent not just on where the noise comes from, but on how exactly it enters the world. The theory's defining equation, the Schrödinger equation, is completely deterministic. There is no noise in it at all. To explain why we observe quantum particles to be noisy, we need some additional principle.

For physicists in the Niels Bohr tradition, the act of observation itself is decisive. The Schrödinger equation

defines a menu of possibilities for what a particle could do, but only when measured does the particle actually do anything, choosing at random from the menu. Identical particles will make different choices, causing the outcomes of fundamental processes to vary in an uncontrollable way. On Bohr's view, quantum noise cannot be explained further. It is what physicist John Wheeler called "an elementary act of creation," with no antecedents. Genesis was not a singular event in the distant past, but an ongoing process that we bring about. We create the world by observing it.

To skeptics such as Einstein, that view is both wonderfully romantic and completely incoherent. Who are "we"? What is "observing"? Physicists and philosophers have spent the better part of a century seeking a less hand-wavy explanation, taking one of two general directions. Maybe quantum noise, like the noise we encounter in daily life, has a meaning that escapes us. It may seem indeterministic, but could be produced by deterministic processes that, for whatever reason,

we can't see. It might, for example, be a consequence of living in one of countless parallel universes and not being able to tell which is ours. The noise, in essence, tells us where we live. All those little upticks and swerves in particle behavior are the quirks that differentiate our universe from others, and they are "noise" inasmuch as our location is pure happenstance, like being put in hotel room 314 rather than 159.

The other basic approach is that quantum noise really is meaningless and quantum theory is as indeterministic as Bohr took it to be, in which case the challenge is simply to tidy up the ill-defined concept of observation. In 1986, three physicists—GianCarlo Ghirardi, Alberto Rimini, and Tullio Weber—proposed that not only is quantum noise meaningless, but experimenters don't trigger it. In fact, nothing does. It shows up, completely unprompted—perhaps once every 100 million years for an individual particle.

Within the interpretational debate, the GRW theory and its variants play a special role. Although they are not the only indeterministic interpretation of quantum mechanics, they *are* the only interpretation that exposes the indeterminism for all to see—as noise—rather than bury it at a subquantum level. GRW is also one of the few interpretations that is testable empirically. Here, at last, is a data-driven test for a debate that hails from the days of Democritus and Plato: Is the universe at its root deterministic or not?

THE GRW THEORY SUPPOSES that noise sporadically strikes particles and causes them to materialize in

one of the locations open to them. This can't happen very often, or else particle behavior would deviate from the Schrödinger equation all the time. Once every 100 million years is enough, because when the blow does come, its effect is greatly amplified by quantum entanglement—the spooky interconnection of particles. A hit on one particle is felt by all those it is entangled with.

This multiplier effect would neatly explain why we observe quantum behavior on the particle level but not in everyday life—why a particle can have no determinate properties but a macroscopic object always does. Although a person or a planet might exist fleetingly in an indeterminate state, just like an isolated particle, it presents a much bigger target and one of its particles will quickly get struck by noise. The noise will fix the location of that particle and all its entangled partners. An object composed of 10^{23} mutually entangled particles will be pinged every 10 nanoseconds or so.

The noise acts on spatial position, but also affects other properties indirectly. Schrödinger's famous both-dead-and-alive cat is quickly forced to be either alive or dead, because those two conditions correspond to different spatial arrangements of particles in the cat's body, and the GRW mechanism will select among them.

The GRW mechanism also demystifies observation. To observe is simply to correlate a particle with some large piece of apparatus, so that the particle's properties become accessible to you. In so doing you expose the particle to the noise that strikes the apparatus. You may not create reality directly, as Bohr thought, but do

The noise, in essence, tells us where we live.



HOTEL MULTIVERSE

Parallel universes could be like hotel rooms, each barely distinguishable from the next—only tiny deviations in the form of noise would tell us which we occupy.

make it possible for the all-pervading noise to act on objects it would otherwise pass over.

The GRW theory, like quantum mechanics itself, is a mathematical formalism and does not prescribe what the world is made of—what philosophers call the ontology. Its creators originally envisioned a particle ontology: an atomistic world. But the theory also works if the universe consists instead of smeared-out matter or force fields. What distinguishes GRW from other interpretations of quantum mechanics is that the noise is untriggered. The hits just happen spontaneously. So, they do not strictly require the existence of anything else. The theory thus opens up a wholly new possibility: that the universe is made purely out of noise.

In this radically minimalist view, proposed by the Irish physicist John Bell in 1987 and later developed by Roderich Tumulka at Rutgers University, the universe is like a darkened auditorium lit up haphazardly by camera flashes: a constellation of disconnected moments rather than stuff with an enduring existence. Because those random moments include all our observations, we could never tell the difference between this

and a continuous universe. We may see a particle in one place and then, later, in another, and it's natural to assume that it existed in between, but maybe we shouldn't. And if the particle doesn't exist in between, we don't really have any particles in the way that term is commonly understood.

This point of view is by no means forced on us, but it has an appealing implication: It is the only known way to resolve the tension between quantum entanglement and relativity theory, short of abandoning one of those theories altogether. Even our most advanced quantum theory, quantum field theory—which was created with the express purpose of reconciling these two theories—doesn't eliminate the conflict that arises during a measurement or equivalent process. As Einstein realized, if quantum physics is indeterministic, what one particle does instantly affects whatever particles it is entangled with. The effect is subtle—it cannot convey a signal—but the word “instantly” is still supposed to be *verboten* in relativity. The whole reason they call it “relativity” theory is that the passage of time is relative to a given observer, so there is no objective sense in which a process could be instantaneous.



SHATTERED BY NOISE In principle a phone screen should be able to heal itself spontaneously. Quantum noise, which disturbs molecules in the screen, might be the reason it doesn't.

One observer might see an effect, another observer at the same position might not, and paradox would ensue.

This contradiction evaporates in GRW because the flashes go off on their own. Nothing causes a flash, not even another flash, so their ordering in time doesn't matter. Whichever flash comes first, the Schrödinger equation will ensure that it is correlated with subsequent flashes. No mechanism operates in space and time to produce this correlation, so relativity simply doesn't apply.

Even the people who proposed the flash picture don't much like it. Without a spatiotemporal mechanism, we seem to lose any hope of a deeper understanding of the correlations and have to accept them as brute fact. But the flash picture is worth thinking about, because it is proof that quantum entanglement and relativity theory are not irreconcilably opposed, and it hints that their reconciliation will require a rethink of what we mean by existence in space and time.

GRW MIGHT EVEN SOLVE entirely separate problems within physics. David Albert, a theoretical physicist turned philosopher at Columbia University, thinks it would help explain the second law of thermodynamics:

the tendency for entropy—loosely defined as the disorderliness of a throng of molecules—to rise in a closed system. The general thinking has been that entropy increases because there are more ways to be disordered than ordered, so if a system starts off nice and neat, it will naturally degenerate into chaos. But textbooks gloss over an important point: It's not assured that disorder is more likely. A system can be arranged in an uncountably infinite number of different ways, and there's no unambiguous way to compare the infinite number of ordered states to the infinite number of disordered ones.

For instance, it's all too easy to smash your smartphone screen by dropping it on the floor. It is also possible for a cracked smartphone screen to heal itself spontaneously if its molecules move in just the right way. Alas, we never see that. That's not because such reversals are intrinsically rare. Indeed there are an infinite number of ways for the molecules to reassemble of their own accord. Physicists typically address this problem by fiat: They add a postulate that establishes a convention for counting states, according to which the reversals are rarer.

Instead, Albert suggests, the issue may not be the

number of ways, but their distribution through the space of possibilities. Reversals are isolated islands within the sea of states that are on their way to becoming more disordered, and he argues that this geography does not depend on the state-counting convention. Drop a smartphone in slightly different ways and the screen will still shatter. But for a smartphone screen to heal itself, the molecules must approach one another in just the right way, and tiny deviations will spoil that. And this is where quantum noise could play a role. It batters the system incessantly and provides those tiny deviations. If the universe ever goes into reverse, noise will quickly jolt it back to normalcy.

For this to work, the noise must be spontaneous—it must not depend on a trigger such as making a measurement. Moreover, the noise must be truly irreducible—it can't reflect our ignorance of finer-scale details, or else the entire problem will recur at that finer scale. And the noise should disturb particles by enough to thwart any reversal. Only GRW, among the sundry proposed explanations of quantum noise, satisfies all three criteria.

GRW IS A POWERFUL THEORY, but none of its experimental predictions has held up so far. It should have all sorts of exotic effects. For instance, it could cause an electron to swerve for no apparent reason and emit an X-ray. Catalina Curceanu of the National Institute of Nuclear Physics, in Italy, and her colleagues showed last year that this doesn't happen more than once every billion years, which rules out GRW's original estimate. The noise would also buffet gravitational-wave detectors such as LIGO. Because such an effect would depend on the size of the detector, it tests not only how often the noise bursts occur but how large a region they affect. The observed noise in these detectors is extremely low, further crimping the theory.

If the GRW mechanism operates, it has to be more complicated than the original conjecture; for instance, particles' susceptibility to noise would depend on their mass. If anything, that might be more plausible. So the theory is still alive. That said, the lack of a clear signal is discouraging. If the theory is the standard-bearer for fundamental indeterminism, the null result makes it a bit more likely that the universe, by default, is deterministic at its root.

Determinism wouldn't strictly eliminate the noise, but merely relocate it. Through the laws of physics, we could trace the origins of each burst of noise—it wouldn't appear out of nowhere, as in the GRW theory, but would occur because particles had been on certain trajectories. In principle, we could unwind those trajectories back to the initial conditions of the universe, which would consist of all the noise of history, lumped together. Whatever the source of noise, it is the raw material of the world, sculpted into rich patterns through processes of evolution and emergence.

In the lab, physicists seek to strip away the noise of the world and expose its simple core. But at some deeper level, they strip away signal to expose noise, and pivot a foundational question on it. So is noise really signal? "To God all is signal," the University of Southern California engineering and law professor Bart Kosko once wrote. If anything, though, the opposite is true: To God all is noise; only to man, who constructs his own meaning, is anything a signal at all. ☯

GEORGE MUSSER is a writer on physics and cosmology and the author of *Spooky Action at a Distance* and *The Complete Idiot's Guide to String Theory*. He is a contributing editor at *Nautilus*, and was previously a senior editor at *Scientific American* for 14 years. He has won the American Institute of Physics Science Writing Award, among others.



Noise Is a Drug and New York Is Full of Addicts

*We may complain about a defining feature of the city,
but we also feed off it*

BY SUSIE NEILSON

AS SOON AS THE DOOR SLAMS, I slide to the floor in a cross-legged position and hold my breath. The room in which I have just barricaded myself looks a bit like *Matilda*'s chokey; a single light bulb casts a sickly yellow glow about the room, its walls lined with triangle-shaped chunks of fiberglass straining against wire mesh. In 15 minutes I will leave this room for the cacophonous world of Manhattan. I should, theoretically, be appreciating this small respite for what it is. Even so, with every second, I feel as if I'm going deeper underwater.

I am sitting in an anechoic chamber, the only one in New York City. Nestled in the hip, angled building of The Cooper Union for the Advancement of Science and Art, the anechoic chamber is where acoustics students, headed by the aptly-named Melody Baglione, conduct research—it's the equivalent of a zero-gravity chamber, only in this case, the variable is sound. The room is designed to be as noise-free as possible; its

chunky walls completely absorb reflections of sound waves, and insulate the space within from all exterior sources of noise. While the chamber is not exactly silent, per se—at 20 decibels, the ambient noise level is quieter than a whisper, but twice as loud as a pin drop—it's almost certainly the quietest space in New York.

And the silence, as they say, is deafening. Sitting in here, it's as if someone has turned the volume up inside of my head. I helplessly observe my mind as thoughts careen across it, stop in the middle and, after a brief, flailing, Wile E. Coyote-esque interval, plummet into the abyss. Desperate for distraction, I check my phone, crack my knuckles, make tiny coughing sounds. Each tiny rupture of quiet attains such specialness, such texture, you can practically touch it. It takes tremendous effort to be silent: yet that's what I'm here to be. In a futile, self-defeating moment, I try to force myself to un-tense. "Just relax!" I scold myself. I am in what you might call a state of withdrawal: and,

ILLUSTRATION BY RYAN PELTIER

like it must be when withdrawing from anything at first, sobriety is deeply uncomfortable.

What am I detoxing from? Noise. I live in the East Village, which is very noisy—illegally noisy. Last year, Jackie Le and Matthew Palmer, acoustics engineering students at Cooper Union, decided to investigate the noise levels of the area near their school for their senior project. Le and Palmer went to various apartments around this neighborhood and, using a decibel meter, calculated the average level of volume coming in through the open windows of multiple apartments, and compared them with “safe” levels defined by New York City’s recently-revised noise code. “In every instance, we found the noise coming into these people’s apartments was above code,” Le says.

If noise is a drug, then it’s a performance drug.

I can vouch for this. I’ve spent this whole year telling anyone who will listen that the hundreds of nights I’ve spent trying to fall asleep in my apartment constitute a Sisyphean Hell of endurance: the iterating, irritating garbage trucks, the construction that starts at promptly 6 a.m. and continues into evening. I make a lot of noise about the noise, and I’m not the only one. Noise is the single greatest quality-of-life complaint New Yorkers have (we lodged 18,000 phone complaints with the Department of Environmental Protection last July alone). We all love to hate the noise. And yet sitting in silence, I do not feel as if I’ve found an escape from pain: I have simply traded it for a new variety. Shockingly, I realize I want to trade back.

In this city of complainers, who could admit to loving something so easy to complain about? Lewis Black, a comedian, couches his praise of noise in a cynical one-liner, noting dryly, “The reason I live in New York

City is because it’s the loudest city on the planet Earth. It’s so loud I never have to listen to any of the shit that’s going on in my own head.”

Black might be on to something. Noise can cause us distress and pain, but it can also help us think, perceive, remember, and be more creative. It turns out that it’s even necessary for our physiological and mental functioning. If it’s a drug, then it’s a performance drug. And New York is full of addicts.

THOUGH IT’S COUNTERINTUITIVE, numerous experiments have demonstrated that the addition of noise can actually improve signal detection. This phenomenon, known as stochastic resonance, was first developed to describe the periodic nature of glacial climate change, and is thought to occur across many nonlinear dynamic systems—including the human brain.

A team led by Keiichi Kitajo, a researcher at RIKEN Brain Institute, first demonstrated this effect in vision. Noise coming into subjects’ left eyes increased their ability to detect a signal with their right. Since then, stochastic resonance has been observed at every level of the nervous system, from sensory receptors to neuronal networks. Researchers at the Wyss Institute at Harvard University have used vibrating insoles to add tactile noise to the soles of feet, improving tactile perception and balance. Auditory noise has been observed to enhance detection of an accompanying signal—which is known as “auditory stochastic resonance.”¹

Auditory noise can heighten our other senses, too. Researchers have found that an “optimal amount” can make your fingers more sensitive to sensations, improve your ability to see contrast and even correct your posture (by enhancing “proprioceptive,” or positioning, signals).² This is known as “cross-modal” stochastic resonance: Noise is a rising tide, lifting all signals. Cross-modal stochastic resonance can also improve memory, and higher-level cognitive processes such as judgment.^{3,4} It may even make us more ingenious.

In 2012, Ravi Mehta and a team of researchers at the University of British Columbia proposed that noise and the brain have a Goldilocksian relationship: Too much or too little impairs thought, but at moderate levels, when it’s “just right,” it makes us more creative.



QUIET ZONE Michael J. Pimpinella, who received his master's degree in engineering at Cooper Union, conducts research in the school's anechoic chamber. At 20 decibels, the chamber is likely the quietest place in New York City.

They subjected this hypothesis, as in the parable, to several tests.

First, the researchers created a noise smoothie from a blend of ambient sounds, including people talking in a cafeteria, vehicle traffic, and distant construction noise. Then they piped it into a room full of undergraduates at various volumes: low (50 db), moderate (70 db), and high (85 db). The students took a Remote Associates Test (or RAT) designed to measure creativity at each volume. The questions consisted of three or four stimulus word prompts, followed by a guess at what the target word is: For example, faced with “shelf,” “read,” and “end,” the correct response was “book.” The number of correct answers reflects the ability to think creatively and associatively.

Students working in the moderate noise level condition generated the most correct answers, an average

of 1.5 more correct answers than in the low noise conditions, and 1.9 more than in the high noise condition. When participants were then asked to come up with creative ideas for a new mattress, low and medium noise participants both generated more ideas than high noise participants, but moderate noise participants' ideas were rated as “more creative” than both low and high noise by a team of independent judges. The researchers made sure to control for the moderate increase of cortisol that can sometimes lead to increased productivity in the presence of noise.

What was going on, the researchers believed, was that the moderate level of noise induced processing disfluency, defined as the loss of “the subjective experience of ease or speed in processing information.” Processing disfluency is basically a measure of mental distance: When it exists, fixating, or thinking

It's as if simply existing in this bustling landscape has helped me streamline and make sense of my own inner world.

closely, becomes just difficult enough that the mind doesn't clench around the particularities of an idea. Instead, it has a looser attitude, and can shift perspectives. The right amount of processing disfluency spurs creative thinking—thoughts with a perfect “creative” distance from their subject. Too much processing disfluency, however, and coherence is lost. This isn't textbook stochastic resonance, because creativity can't be boiled down to signal detection. But, just like textbook cases, an optimum exists, after which benefits fall away parabolically.

The optimal level for creative thinking, Mehta found, is 70 db—about the level of a crowded café.⁵ Or traffic in midtown Manhattan.

DANNIELLE TEGEDER IS a contemporary artist best known for her abstract blueprints of Utopian cities, and has had her work presented in over 100 gallery exhibitions. She has several pieces in the permanent collections of New York's Museum of Modern Art, Chicago's Museum of Contemporary Art, and The Weatherspoon Museum of Art in Greensboro. Her studio? It's in the heart of Times Square.

“I don't think you could get a louder and crazier place in all of New York City,” she says. However, when she attempts to just “get away from it all” she finds herself unable to work. “I go to a lot of artist residencies upstate, and I become completely immobilized when I'm there,” she says. “I find that it really brings my creativity level down, being in a bucolic environment. It's just too calm.”

The focus of Tegeder's work is city living, and “how pathways are made through pedestrians and traffic and subways.” New York's noise is “exciting and stimulating,” she says, and it gives her something. “Weirdly, being in such a loud productive space in the middle of the city connects into my thinking and being. There's a certain agitation level I get, because I commute during rush hour, but there's still something I get from that. I don't want to say it wakes you up, but it pushes you to think in a different way for sure.”

William Parker, a composer and double bassist living in the East Village and a prominent member of the New York City avant garde jazz scene, believes the city's noises are an integral part of his music. Growing up in the Bronx, he says, “I really started getting into



ABOVE Danielle Tegeder, a contemporary artist best known for her abstract representations of Utopian cities, says her studio's Times Square location provides her with the noise necessary for continued inspiration.

OPPOSITE PAGE Tegeder's pieces, like this one, called *Nocturnal Blue Machine Plan Universe with Method Angle Codes* (2014), often function as abstract plans for Utopian cities. “I always joke that I'd love to go to an artist residency in Tokyo or another big city,” she says.

IMAGES COURTESY OF DANNIELLE TEGEDER



listening to, not what I was focused on, but to peripheral sounds.” His relationship with noise deepened as his career took off. “Later on, as I started studying music, [peripheral noise] became very important to me.” (See *Rooted in Sound*, page 77.)

For Tegeder, Parker, and many of the city’s residents, the noise of New York is a comfort, an inspiration, even a declaration of identity. The city’s own noise code tips its hat to this fact, saying on its first page that it aims to balance health needs with New York’s “important reputation ... as a vibrant, world-class city that never sleeps.” The city’s noise pulls on the psyche, a jangling byproduct and energetic hum that feeds on itself.

As the city gets louder, it is also getting more creative. The Center for an Urban Future 2013 report “Creative New York” found that, “while traditional economic drivers like finance and legal services have stagnated in recent years, several creative industries have been among the fastest growing segments of the city’s economy.” Employment in film and television production increased 53 percent over the past decade. Architecture (33 percent growth), performing arts (26 percent), advertising (24 percent), visual arts (24 percent), and applied design (17 percent) all outpaced the city’s overall employment growth, which was 12 percent. Today the city is home to 14,145 creative businesses and nonprofits, up 18 percent from a decade ago; there are more Etsy sellers than yellow cab drivers.

All of which doesn’t mean that every creative type will benefit from the Big Apple’s din. The “just-right” level of noise will differ from one person to the next, following their levels of internal noise: the symphony (or cacophony) created by the interaction of organs, electrophysiological signals between skeletal muscles, and conversations between our neurons.⁶ We know that internal and external noises combine and compete in our bodies and minds, and this balance can tilt one way or the other. How can you tell if you’ll like it? It helps if you have ADHD.

People with ADHD often have low neural dopamine levels. This leads them to have memory and focus issues, and to seek excess external stimulus. Noise can have minor medicative effects for them; Göran Söderland and a team of researchers found that subjects with ADHD performed better on cognitive tasks under 81 db

level of ambient noise (about the loudness of a garbage disposal), while control groups’ performance declined.⁷ “Participants with low dopamine levels (ADHD) require more noise for optimal cognitive performance compared to controls,” they write.

Again, there was a Goldilocks effect. “Strong, salient, irrelevant stimuli may easily disrupt concentration, leading to attentional problems, whereas an impoverished environment may be compensated for

If you’re a New Yorker who finds herself in the suburbs, white noise could be your nicotine patch.

by hyperactivity. However, moderate levels of arousing stimuli may be beneficial for cognitive performance.” Söderland and his team believed this boils down to the behavior of dopamine, the neurochemical intimately tied into the mechanism of ADHD. By enhancing the difference between internal noise and external stimulation, it helps us separate meaningful external cues from meaningless internal neurological and chemical rumblings. In other words, our signal-to-noise ratio goes up.

In people with ADHD, dopamine is usually too low—until environmental stimuli come in. Then, dopamine goes haywire, flooding the synaptic cleft and drowning out the signal, then getting drawn back into the system, creating yet more noise and confusion. A moderate level of constant noise acts like the classic stochastic resonant system: A signal gets enhanced and stays there. Dopamine rises on the tide of noise, but gently, without flooding. ADHD medication changes this balance, and patients often report increased sensitivity to external noise.

New York may just be the perfect ADHD pill, dialing up the noise in the heads of individuals with low internal noise, and helping them dial down the chaos they feel. Highly creative people often suffer from ADHD, and I’ve been diagnosed with it. Ever since moving to

New York, I've experienced an unprecedented balance of productivity and peace—it's as if simply existing in this bustling landscape has helped me streamline and make sense of my own inner world.

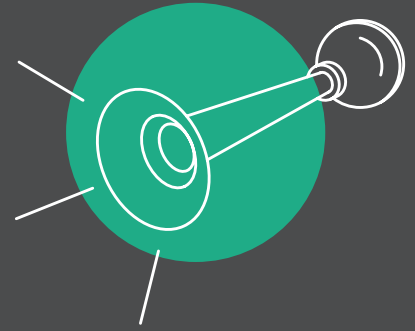
HERE'S THE THING ABOUT NOISE, though—you miss it when it's gone.

To live in New York means to get habituated to the noise of everyday life here. Researchers have seen the effect happen over time. As a neighborhood becomes more homogenous, and its residents sync their noise patterns, noise complaints tend to go down. This may explain why, controlling for other factors, gentrifying areas of the city display higher levels of noise complaints. City residents stop consciously recognizing noise as novel, and it becomes background, even if their bodies don't always recognize it as such.

Arline Bronzaft, an environmental psychologist with a specialty in the effects of noise pollution, cautions that noise tolerance can be harmful. "People use the phrase, 'I get used to it—I walk the streets and I get used to the noise,'" she told *The New York Times* in 2013. "It means you've adapted to the noise. When you're dealing with something, you're using energy to cope with the situation. Guess what? That's wear and tear on your body. So when you hear someone say, 'I'm dealing with it,' I say, 'Yes, but at what cost?'" All those jackhammers, sirens, and late-night garbage trucks are working their way into your teeth, your ears, your brain, and your heart. Studies conducted in industrial settings have long demonstrated relationships between noise exposure and cardiovascular disorders. In 2006, Dr. Hildegaard Niemann found that people exposed to neighborhood noise lived shorter lives, thanks to increased risk for heart disease, depression, migraines, and respiratory system problems.⁸

That's not to mention hearing loss, which occurs after prolonged exposure to all sounds louder than 85 db, says Charles Shamoon, an assistant counsel at the DEP who co-authored the city's revised noise code in 2007. These effects are further compounded by stress.

Sometimes, though, nothing is as loud as quiet. When he moved home after graduation, Matthew Palmer, the Cooper Union student whose project rattled out the entire East Village, found that he missed the noise that used to jar him, and had trouble sleeping.



Rooted in Sound

William Parker, a resident of the East Village, is a jazz composer and bassist. Growing up in the Bronx, Parker fed on the sounds of human activity—like children playing baseball and skipping rope—and the peripheral environmental sounds of city life, like the wicker seats on the old Third Avenue El Train or a bus driver's change dispenser.

Can you see any ways you've incorporated the sounds you hear around you into how you play?

I've had birds in this house for years. I wanted to hear the way they phrase, but ... I didn't listen to the birds and transcribe what they did. All I know is that the birds are not singing, "dah dah dah dah [does a perfect scale], they're singing "shp, meep, nuh," so that gives me confirmation when people say "that music you're playing is wild, it's crazy," and I say "yeah, it sounds like the birds. They play wild." So it gives me a confirmation that what we're doing is not avant-garde. If I'm avant-garde then these birds are avant-garde. The dolphins are avant-garde. All of nature's avant-garde. So, cool! Let me be avant-garde.

Continues on the next page

As you got older, how did the way you felt about the sounds in your environment change?

Perhaps we can add birds to the list of sounds I listened to. And then of course very loud sounds like fire trucks and ambulances. But the sounds I loved constantly remained an inspiration to me as far as a part of your peripheral background.



Can you tell me about how listening to your peripheral sound was important to music?

When we're focused on something, our range of hearing and seeing is limited. When we look peripheral, peripheral is very wide. So it was a matter of seeing that there is a melody, and then there are the little sounds: the burp, the bleep, the half sounds, the in-between notes. You begin to distinguish between a sound and a note, and for me, music is sound, not notes. It helped me get an idea of widening the scope and range of the vocabulary of music, that the vocabulary of music was not locked in.

—Peter Hess

“Every time I come to visit my family, it feels way too quiet.” The experience is a common one for people who move to the suburbs from the city. They find it difficult to sleep; their brains, in the absence of the moderate external noise they’re used to, ramp up their internal noise, and become increasingly sensitive to the smallest sounds.

After the city, a quiet environment can produce “sensory underload,” a lowered level of stimulation that brings with it a higher level of noisy neural activity. In a miniature everyday version of this effect, people trying to get to sleep at night often report internal overstimulation, or “racing thoughts”—in lieu of external stimuli, it’s as if the noise in their head is dialed up, and thoughts all crowd in at once. Physicians often prescribe white noise—a moderate, constant external noise source—to help calm racing thoughts. If you’re a New Yorker who finds herself in the suburbs, white noise could be your nicotine patch. Or, if you’re back in the city, just crack open a window.

In the essay collection *Goodbye to All That*, a group of ex-New Yorkers reflect on what initially drew them to the city—“the crush of subway crowds, the streets filled with manic energy, and the certainty that this is the only place on Earth where one can become exactly who she is meant to be”—and the subsequent need to leave.⁹ Once they do leave, each of them finds a residual ache, a withdrawal effect. Nowhere is this nostalgia more palpable than in Joan Didion’s description of her walk home from work, which she presents to us as a baffling bouquet of sensory noise: “I could taste the peach and feel the soft air blowing from a subway grating on my legs and I could smell lilac and garbage and expensive perfume and I knew that it would cost something sooner or later ...”

As for myself, I found the brief respite from the city in the anechoic chamber invigorating. As I leave the chamber, I feel my vision sharpen. Every part of my body feels more alert, but still relaxed. I tell Baglione that I feel like I’ve just been in a spa. “I could do this every day,” I say. She looks at me like I’m crazy. Going cold turkey was hard for a bit. But then the fuzz inside of my brain smoothed out. After about 5 minutes, I relaxed. I realized I could hear my blood circulating throughout my body. My thoughts slowed, reaching solid conclusions.

Outside Cooper Union, the city noise assaults me once more; there's a drill placed uncannily close to the school's entrance, and a man is jackhammering away. I reach into my backpack pocket and pull out Baglione's parting gift: a pair of earplugs. I spend the rest of the day walking around with them stuffed inside my ears. I only take them out once—when I see a man playing a painted piano in Washington Square Park, his fingers pounding the keys. ☺

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REFERENCES

1. Ward, L.M., MacLean, S.E., & Kirschner, A. Stochastic resonance modulates neural synchronization within and between cortical sources. *PLoS One* **5**, e14371 (2010).
2. Lugo, E., Doti, R., & Faubert, J. Ubiquitous crossmodal stochastic resonance in humans: Auditory noise facilitates tactile, visual, and proprioceptive sensations. *PLoS One* **3**, e2860 (2008).
3. Herweg, N.A. & Bunzeck, N. Differential effects of white noise in cognitive and perceptual tasks. *Frontiers in Psychology* **6**, 1639 (2015).
4. Usher, M. & Feingold, M. Stochastic resonance in the speed of memory retrieval. *Biological Cybernetics* **83**, L11-L16 (2000).
5. Mehta, R., Zhu, R., & Cheema, A. Is noise always bad? Exploring the effects of ambient noise on creative cognition. *Journal of Consumer Research* **39**, 784-799 (2012).
6. Faisal, A.A., Selen, L.P.J., & Wolpert, D.M. Noise in the nervous system. *Nature Reviews Neuroscience* **9**, 292-303 (2008).
7. Söderlund, G., Sikström, S., & Smart, A. Listen to the noise: Noise is beneficial for cognitive performance in ADHD. *Journal of Child Psychology and Psychiatry* **48**, 840-847 (2007).
8. Baughman, B. Noise pollution hard on heart as well as ears. NPR (2011).
9. Botton, S. (Ed.) *Goodbye to All That* Hachette Book Group, New York, NY (2013).

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AT THIS YEAR'S PRESS CONFERENCE announcing Memphis Grizzlies guard Mike Conley's second win of the NBA Sportsmanship Award, the questions from the press were downright nostalgic.

"What in today's game defines sportsmanship?" one reporter asked. "Maybe you don't see guys do it as much anymore." Another complained about players' public behavior. "You don't see guys nowadays—you've done it but—they don't compliment each other through the media anymore."

When we think of sports science and technology, the physics of a curveball or weave of a carbon-fiber shoe might come to mind—the hardware. But there is also a high technology, of sorts, in the software of sport. Without it, would we understand sportsmanship, and what it means to love playing more than winning?

In a society that is driven by competition at every level, and is made up of people who use play to help define themselves, that is a valuable contribution. It's enough to make you wistful.

Welcome to "Sport."

—MS

"Honold really does have an extraordinary brain, and he really could be feeling no fear up there. None at all."

J.B. MACKINNON

"The Strange Brain of the World's Greatest Solo Climber" p.82

Sport

THE RULES OF PLAY



The Strange Brain of the World's Greatest Solo Climber

Alex Honnold doesn't experience fear like the rest of us

BY J.B. MACKINNON

PHOTOGRAPHY BY JIMMY CHIN

SLICE OF HEAVEN Alex Honnold climbs an overhanging rock known as Heaven in Yosemite, 3,000 feet above the valley floor. "When I'm looking up at Heaven," Honnold said, "I have to psychologically commit to it. Decide: Am I ready to do this? Do I want to do this?"

ALEX HONNOLD HAS his own verb. “To honnold”—usually written as “honnolding”—is to stand in some high, precarious place with your back to the wall, looking straight into the abyss. To face fear, literally.

The verb was inspired by photographs of Honnold in precisely that position on Thank God Ledge, located 1,800 feet off the deck in Yosemite National Park. Honnold side-shuffled across this narrow sill of stone, heels to the wall, toes touching the void, when, in 2008, he became the first rock climber ever to scale the sheer granite face of Half Dome alone and without a rope. Had he lost his balance, he would have fallen for 10 long seconds to his death on the ground far below. One. Two. Three. Four. Five. Six. Seven. Eight. Nine. Ten.

Honnold is history’s greatest ever climber in the free solo style, meaning he ascends without a rope or protective equipment of any kind. Above about 50 feet, any fall would likely be lethal, which means that, on epic days of soloing, he might spend 12 or more hours in the Death Zone. On the hardest parts of some climbing routes, his fingers will have no more contact with the rock than most people have with the touchscreens of their phones, while his toes press down on edges as thin as sticks of gum. Just watching a video of Honnold climbing will trigger some degree of vertigo, heart palpitations, or nausea in most people, and that’s if they can watch them at all. Even Honnold has said that his palms sweat when he watches himself on film.

All of this has made Honnold the most famous climber in the world. He has appeared on the cover of *National Geographic*, on *60 Minutes*, in commercials for Citibank and BMW, and in a trove of viral videos. He might insist that he feels fear (he describes standing on Thank God Ledge as “surprisingly scary”), but he has become a paramount symbol of fearlessness.

He also inspires no shortage of peanut-gallery commentary that something is wrong with his wiring. In 2014, he gave a presentation at Explorers Hall, at the National Geographic Society headquarters in Washington, D.C. The audience was there to hear from climbing photographer Jimmy Chin and veteran explorer Mark Synnott, but above all they had gathered to gasp at tales about Honnold.

Synnott got the biggest response from a story set in Oman, where the team had traveled by sailboat to visit the remote mountains of the Musandam Peninsula, which reaches like a skeletal hand into the mouth of the Persian Gulf. Coming upon an isolated village, they went ashore to mix with the locals. “At a certain point,” Synnott said, “these guys start yelling and they’re pointing up at the cliff. And we’re like, ‘What’s going on?’ And of course I’m thinking, ‘Well, I’m pretty sure I know.’”

Up came the photograph for the gasp from the crowd. There was Honnold, the same casual dude who was sitting on stage in a grey hoodie and khakis, now looking like a toy as he scaled a huge, bone-colored wall behind the town. (“The rock quality wasn’t the best,” Honnold said later.) He was alone and without a rope. Synnott summed up the villagers’ reaction: “Basically, they think Alex is a witch.”

When the Explorers Hall presentation concluded, the adventurers sat down to autograph posters. Three lines formed. In one of them, a neurobiologist waited to share a few words with Synnott about the part of the brain that triggers fear. The concerned scientist leaned in close, shot a glance toward Honnold, and said, “That kid’s amygdala isn’t firing.”

ONCE UPON A TIME, Honnold tells me, he would have been afraid—his word, not mine—to have psychologists and scientists looking at his brain, probing his behavior, surveying his personality. “I’ve always preferred not to look inside the sausage,” he says. “Like, if it works, it works. Why ask questions about it? But now I feel like I’ve sort of stepped past that.”

And so, on this morning in March, 2016, he is laid out, sausage-roll style, inside a large, white tube at the Medical University of South Carolina, in Charleston. The tube is a functional magnetic resonance imaging (fMRI) brain scanner, essentially a huge magnet, which detects activity in the brain’s different regions by tracing blood flows.

Months earlier, I had approached Honnold about taking a look at his much admired, much maligned brain. “I feel totally normal, whatever that means,” he said. “It’d be interesting to see what the science says.”

“Why does he do this?”

The cognitive neuroscientist who volunteered to carry out the scan is Jane Joseph, who in 2005 was one of the first people to perform fMRIs on high sensation seekers—people who are drawn to intense experiences and are willing to take risks to have them. Psychologists have studied sensation seeking for decades because it often leads to out-of-control behaviors such as drug and alcohol addiction, unsafe sex, and problem gambling. In Honnold, Joseph saw the possibility of a more remarkable typology: the super sensation seeker, who pursues experiences at the outer limits of danger, yet is able to tightly regulate the mind and body's responses to them. She is also simply in awe of what Honnold can do. She had tried to watch videos of him climbing ropeless, but being a low sensation seeker herself, found them overwhelming.

“I’m excited to see what his brain looks like,” she says, sitting in the control room behind leaded glass as the scan begins. “Then we’ll just check what his amygdala is doing, to see: Does he really have no fear?”

Often referred to as the brain’s fear center, the amygdala is more precisely the center of a threat response and interpretation system. It receives information on a straight pathway from our senses, which allows us to, for example, step back from an unexpected precipice without a moment’s conscious thought,

and triggers a roster of other bodily responses familiar to almost everyone: racing heartbeat, sweaty palms, tunnel vision, loss of appetite. Meanwhile, the amygdala sends information up the line for higher processing in the cortical structures of the brain, where it may be translated into the conscious emotion we call fear.

An initial anatomical scan of Honnold’s brain appears on MRI technician James Purl’s computer. “Can you go down to his amygdala? We have to know,” says Joseph. Medical literature includes cases of people with rare congenital conditions, such as Urbach-Wiethe disease, which damage and degrade the amygdala. While these people generally don’t experience fear, they also tend to show other bizarre symptoms, such as a total lack of concern for personal space. One individual was comfortable standing nose-to-nose with others while making direct eye contact.

Purl scrolls down, down, through the Rorschach topography of Honnold’s brain, until, with the suddenness of a photo bomb, a pair of almond-shaped nodes materialize out of the morass. “He has one!” says Joseph, and Purl laughs. Whatever else explains how Honnold can climb ropeless into the Death Zone, it isn’t because there’s an empty space where his amygdala should be. At a glance, Joseph says, the apparatus seems perfectly healthy.



NO BIG DEAL Technician James Purl and neuroscientist Jane E. Joseph put Honnold into an MRI tube to measure his brain's fear levels. After looking at gruesome and arousing images inside, he commented, "I was like, whatever."

Inside the tube, Honnold is looking at a series of about 200 images that flick past at the speed of channel surfing. The photographs are meant to disturb or excite. "At least in non-Alex people, these would evoke a strong response in the amygdala," says Joseph. "I can't bear to look at some of them, to be honest." The selection includes corpses with their facial features bloodily reorganized; a toilet choked with feces; a woman shaving herself, Brazilian style; and two invigorating mountain-climbing scenes.

"Maybe his amygdala is not firing—he's having no internal reactions to these stimuli," says Joseph. "But it could be the case that he has such a well-honed regulatory system that he can say, 'OK, I'm feeling all this stuff, my amygdala is going off,' but his frontal cortex is just so powerful that it can calm him down."

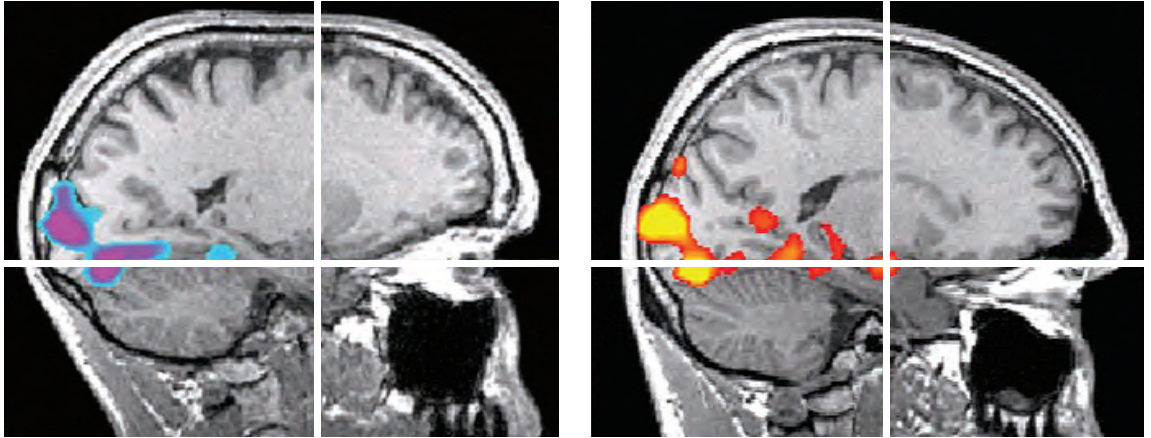
There is also a more existential question. "Why does he do this?" she says. "He knows it's life-threatening—I'm sure people tell him every day. So there may be some kind of really strong reward, like the thrill of it is very rewarding."

To find out, Honnold is now running through a second experiment, the "reward task," in the scanner.

"I'm excited to see what his brain looks like," the neuroscientist says. "Does he really have no fear?"

He can win or lose small amounts of money (the most he can win is \$22) depending on how quickly he clicks a button when signaled. "It's a task that we know activates the reward circuitry very strongly in the rest of us," Joseph says.

In this case, she's looking most closely at another brain apparatus, the nucleus accumbens, located not far from the amygdala (which is also at play in the reward circuitry) near the top of the brainstem. It is one of the principal processors of dopamine, a neurotransmitter



ABSENCE OF FEAR Scans compare Honnold's brain (left) with a control subject's (right), a rock climber of a similar age. Crosshairs mark the amygdala, a group of nuclei involved in generating fear. As both climbers look at the same arousing images, the control subject's amygdala glows, while Honnold's remains inert, showing no activity whatsoever.

that arouses desire and pleasure. High sensation seekers, Joseph explains, may require more stimulation than other people to get a dopamine hit.

After about half an hour, Honnold emerges from the scanner looking sleepily doe-eyed. Raised in Sacramento, California, he has a refreshingly frank manner of speaking, and an oddly contradictory demeanor that might be described as intensely laid back—his nickname is No Big Deal, which is his assessment of almost every experience he undergoes. Like most expert climbers, he is leanly muscled, more like a fitness buff than a body builder. The exceptions are his fingers, which permanently look as though they've just been slammed in a car door, and his forearms, which bring to mind Popeye.

"Looking at all those images—does that count as being under stress?" he asks Joseph.

"Those images that you saw are used pretty widely in the field for inducing fairly strong arousal responses," Joseph replies.

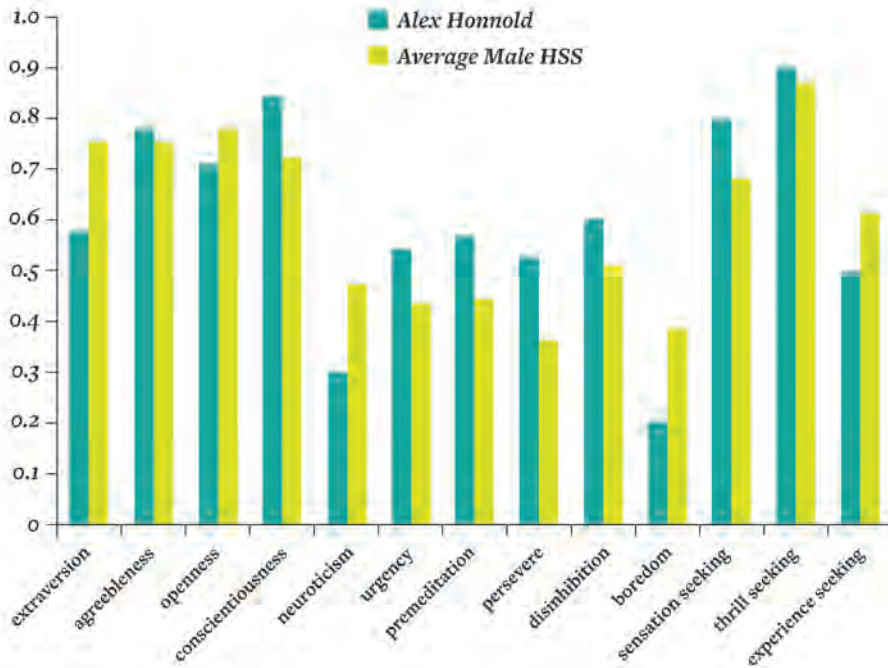
"Because, I can't say for sure, but I was like, *what-ever*," he says. The photographs, even the "gruesome burning children and stuff" struck him as dated and jaded. "It's like looking through a curio museum."

A MONTH LATER, having studied Honnold's scans, Joseph is on a patchy conference call to Shanghai, China, where Honnold is en route to climb, with ropes, the underbelly of the stalactite-spangled Great Arch of Getu. Unusually for Honnold, his voice betrays tiredness and even stress. A few days earlier, near Index, Washington, he had climbed an easy route to set up ropes for his girlfriend's parents. As his girlfriend, Sanni McCandless, lowered him back to the ground, he suddenly dropped the final 10 feet to land in a jumble on the rocks below—the rope wasn't long enough to get him to the ground, and the end had slipped through McCandless' hands. "It was kind of just a botch," he says. He suffered compression fractures in two vertebrae. It was the most serious accident of his rock climbing life, and it came while he was tied into a rope.

"What do all the brain pictures mean?" Honnold asks, looking at the brightly colored fMRI images that Joseph has sent him. "Is my brain intact?"

"Your brain's intact," says Joseph. "And it's quite interesting."

Even to the untrained eye, the reason for her interest is clear. Joseph had used a control subject—a high-sensation-seeking male rock climber of similar age to Honnold—for comparison. Like Honnold, the control



A WARNING SIGN Joseph was surprised by some of the results of Honnold's personality survey. Despite his extraordinary calm and focus while climbing, he showed a higher level of urgency and disinhibition than the average sensation seeker, suggesting he has a risky impulsivity.

subject had described the scanner tasks as utterly unstimulating. Yet in the fMRI images of the two men's responses to the high-arousal photographs, with brain activity indicated in electric purple, the control subject's amygdala might as well be a neon sign. Honnold's is gray. He shows zero activation.

Flip to the scans for the monetary reward task: Once again, the control subject's amygdala and several other brain structures "look like a Christmas tree lit up," Joseph says. In Honnold's brain, the only activity is in the regions that process visual input, confirming only that he had been awake and looking at the screen. The rest of his brain is in lifeless black and white.

"There's just not much going on in my brain," Honnold muses. "It just doesn't do anything."

To see if she was somehow missing something, Joseph had tried dialing down the statistical threshold.

She finally found a single voxel—the smallest volume of brain matter sampled by the scanner—that had lit up in the amygdala. By that point, though, real data was indistinguishable from error. "Nowhere, at a decent threshold, was there amygdala activation," she says.

Could the same be happening as Honnold climbs ropeless into situations that would cause almost any other person to melt down in terror? Yes, says Joseph—in fact, that's exactly what she thinks is going on. Where there is no activation, she says, there probably is no threat response. Honnold really does have an extraordinary brain, and he really could be feeling no fear up there. None at all. None whatsoever.

HONNOLD HAS ALWAYS REJECTED the idea that he is fearless. To the wider world, he is known as a figure of preternatural calm as he hangs by his fingertips on the



ON EDGE In 2008, “as a matter of pride,” Honnold walked across Thank God Ledge, while free-climbing Half Dome in Yosemite. Later, he wrote, “Walking face-out across Thank God Ledge is surprisingly scary.”

fine line between life and death. No one was watching, though, more than a decade ago, when he was 19 years old, standing at the base of his first major ropeless rock climb: Corrugation Corner, near Lake Tahoe, California. On the arcane grade scale climbers use to describe a route’s difficulty, Corrugation Corner is a 5.7—more than 15 points easier than Honnold’s maximum skill level at the time. Still, the line is 300 feet high. “You’d fall and die,” Honnold says.

In order to free solo the route, he first had to have the desire to do so. “I think that the unique thing isn’t my ability to solo, I think the unique thing is really wanting to,” Honnold says. His heroes were ropeless climbers like Peter Croft and John Bachar, who had set new standards in the style in the 1980s and ’90s. (Honnold was also intensely shy, which made it difficult for him to find partners for roped climbing.) He saw their

photographs in climbing magazines and knew—he just *knew*—that he wanted to put himself in those same kinds of positions: wildly exposed, potentially deadly, totally under control.

He is, in other words, the classic high sensation seeker. On the same day he climbed into the MRI tube, Honnold also answered several surveys used by psychologists to measure the degree of a person’s sensation seeking. He was asked to agree or disagree with statements such as, *I would enjoy the sensation of skiing very fast down a high mountain slope* (“I frickin’ love skiing fast downhill,” he says); *I would enjoy parachute jumping* (“I learned how to skydive”); and *I like to explore a strange city or section of town myself, even if it means getting lost* (“That’s everyday life for me”). He once filled out a similar questionnaire at an outdoors industry show, in which the question about whether he



Nowhere in the fear
center of Honnold's
brain could the
neuroscientist
spot activity.

would ever consider rock climbing was illustrated by a photo of: Alex Honnold.

Yet Honnold ended up scared, really scared, on Corrugation Corner. He clung to the big, friendly holds. “I overgripped the shit out of it,” he says. Obviously, though, he didn’t give up after that first experience. Instead, Honnold donned what he called “mental armor” and crossed the threshold of fear again and again. “For every hard pitch I’ve soloed I’ve probably soloed a hundred easy pitches,” he says.

One by one, acts that had seemed outrageous to him began to seem not so crazy: soloing moves in which he hangs only by his fingers, for example, with his feet swinging in the open air, or, as he did in June on a notorious route called The Complete Scream, climbing ropeless up a pitch that he had never ascended before. In 12 years of free solos, Honnold has broken holds, had his feet slip, gotten off-route into unknown terrain, been surprised by animals like birds and ants, or just suffered “that fraying at the edges, you know, where you’ve just been up in the void too long.” But because he managed to deal with these problems, he gradually dampened his anxieties about them.

To Marie Monfils, who heads the Monfils Fear Memory Lab at the University of Texas at Austin, Honnold’s process sounds like an almost textbook, if obviously extreme, approach to dealing with fear. Until recently, Monfils says, most psychologists believed that memories—including fear memories—became “consolidated,” or unchangeable, soon after they were acquired. In just the past 16 years, that understanding has shifted. Research has shown that every time we recall a memory, it undergoes reconsolidation, meaning we are able to add new information or a different interpretation to our remembrance, even turning fearful memories into fearless ones.

Honnold keeps a detailed climbing journal, in which he revisits his climbs and makes note of what he can do better. For his most challenging solos, he also puts a lot of time into preparation: rehearsing the moves and, later, picturing each movement in perfect execution. To get ready for one 1,200-foot-high ascent at the cutting edge of free soloing, he even visualized everything that could possibly go wrong—including “losing it,” falling off, and bleeding out on the rock below—to come to terms with those possibilities before he left the ground.

Honnold completed that climb, known as Moonlight Buttress, in Utah’s Zion National Park, about 13 years after he started climbing, and four years after he started soloing.

Revisiting memories to cast them in a new light, Monfils says, is almost certainly something that we do all the time without being aware of it. But doing so actively, as Honnold did, is better—“a beautiful example of reconsolidation.”

Visualization—which we might think of as *pre-consolidation*, whereby a person pictures a future event rather than a past one—functions in much the same way. “To review move after move, you’d expect that he did consolidate his motor memory and as a result probably had an increased sense of competence,” Monfils says. Feelings of competence, in turn, have been shown to reduce anxiety, which helps to explain why, for example, people who are fearful of public speaking (as Honnold used to be, by the way) feel less anxious about it as they do it more often and develop their skills.

“It’s better over time if you can put yourself in a situation where you experience some fear, but you overcome it, and you do it again and again and again,” Monfils says. “It’s hard, and it’s a big investment, but it becomes easier.”

The amygdala, again, plays a key role. Monfils offers an example from her own life. She has a genuine phobia of snakes. One day, canoeing with friends at the edge of a lake, she spotted a water moccasin, which is a venomous species, hanging on a branch. Monfils started screaming, paddled frantically to the middle of the lake, and avoided outdoor adventures for a year afterward. Then, on a hike, she ran into another snake and freaked out again. This time, she applied her expertise to the problem. She made efforts to lie down and recall the episode in calm and logical terms. She reconsolidated her scary memory into something more useful. Just one week later, she suppressed her fear, mustered her courage, and got out on the trails again.

“The amygdala probably activates a split second before you explicitly remember, ‘ah, this is where I saw the snake,’ ” she says. “So you feel your hands being sweaty and you feel this flood of emotions. And it requires this explicit engagement on your part to involve your prefrontal cortex and say, ‘the snake is not here now, in fact the snake didn’t do anything when it



SOLO Honnold says he began climbing solo because he was “too shy to go up to strangers at a crag and ask if they’d like to rope up with me.” Here in Oman, on the Arabian Peninsula, he “deep-water solos,” climbing that usually ends with a drop into the water below.

was there, it just happened to be there.’ And then progressively what this does is that your prefrontal cortex quenches this amygdala-on-fire. It puts the information in its appropriate context to say, ‘there’s no need to be afraid here, you can just walk on the path.’”

WITHOUT GOING BACK in time to scan Honnold’s brain before he started down his own path as a free soloist, there is no way to know how much nature and how much nurture went into his fearlessness. But a few possibilities seem safe to rule out.

Joseph LeDoux, a neuroscientist at New York University who has been studying the brain’s response to threats since the 1980s, tells me he has never heard of any person being born with a normal amygdala—as Honnold’s appears to be—that shows no sign of

activation. Addressing a possibility raised by Honnold that a person could burn out his amygdala from overstimulation, LeDoux says, “I don’t think that could happen.” Still, when I describe Honnold’s total absence of amygdala activation during the scan tasks, LeDoux’s response is, “That sounds pretty impressive.”

There is genetic variability between individuals in all parts of the brain, LeDoux says, so it’s a fair bet that Honnold’s threat-response circuitry started out on the cool end of the spectrum—which would explain why his younger self saw a powerful appeal, rather than lethal danger, in the photographs of his ropeless climbing heroes. At least as important as the brain that Honnold was born with, however, is the one that he has wired for himself through thousands of hours of risk-taking. “His brain is probably predisposed to

Has Honnold's new awareness of his atypical brain affected his sense of self?

be less reactive to threats that other people would be naturally responsive to, simply because of the choices he's made," LeDoux says. "On top of that, these self-imposed strategies that he's using make that even better, or stronger."

Genetics has a clearer role in the personality traits that have helped motivate Honnold's ropeless climbing. Sensation seeking is thought to be partly heritable, and can be passed down from parents to their children. The trait is associated with lower anxiety and a blunted response to potentially dangerous situations. One result can be a tendency to underestimate risks, which a recent study linked to an imbalance caused by low amygdala reactivity and less effective inhibition of sensation seeking by the prefrontal cortex.

Joseph's own research doesn't look at individual cases (she considers her scan of Honnold an "observation"), but she has noted "greatly diminished" amygdala responsiveness among some cohorts of high sensation seekers—and Honnold is a *very* high sensation seeker. Compared against the data pool collected by

Joseph's lab, Honnold is twice as sensation-seeking as the average person, and fully 20 percent higher than the average high sensation seeker. The most likely explanation for his flatline amygdala activation in the scanner, Joseph says, is that the tasks she set for him simply were not strong enough tea.

Honnold also scores as exceedingly conscientious, associated with the ability to concentrate, remain focused on a task, and see things through. He also surveyed high in premeditation, his typical *modus operandi*, and very low in neuroticism, making him unlikely to ruminate over unlikely outcomes or risks that are impossible to manage. "If you don't have any fear to begin with," Honnold says, "there's a lot less to control."

"He has the traits that enable him to be incredibly focused, and incredibly patient, but at the same time totally sensation seeking," Joseph says. A single example is a long way from proving a theory, but a guy who free solos into the Death Zone, and yet goes by the nickname No Big Deal, is compelling evidence of Joseph's super-sensation-seeker hypothesis when it

comes to Honnold.

“The idea of the super sensation seeker—who is defined by having this really strong motivation to pursue these kinds of positive and thrilling experiences, but at the same time having the control and the regulation—is important. I think it could teach us a lot about potentially treating substance-abuse disorder, anxiety disorders, and coming up with strategies that people can use,” she says. “Potentially just talking with Alex, you could envision a new kind of intervention.”

For example, many high sensation seekers’ problematic behaviors involve intense experiences that can be pursued impulsively and without obvious immediate consequences, such as binge drinking or drug use. (Honnold has always avoided alcohol and drugs, and doesn’t drink coffee.) Joseph wonders if that energy could be redirected into high-arousal activities—such as rock climbing, but with protective gear—that by their nature involve constraint, premeditation, and specific goals, reinforcing different life patterns.

At the very least, it might be possible for any one of us to work a little bit of Honnold’s magic. You may not have the traits of a super sensation seeker, or be able to quench your amygdala on command, but with conscious effort and gradual, repeated exposure to what you fear, any one of us might muster courage that we didn’t know we had.

Honnold’s personal challenge is different, with higher stakes. As remarkably well wired as he is—or has made himself to be—there are risk factors in the mix.

When I ask Honnold to describe the ideal free-solo psychological experience, he says, “You get into positions where you’re like, this is so outrageous, you know? Like, this is so amazing. That’s the whole point, really—to be up in some position that makes you feel like a total hero.”

Yet he also tells me that easier, day-to-day soloing (the kind that most rock climbers would still consider to be an extreme activity) has lost some of its novelty, and even life-list solos sometimes leave him underwhelmed. “I didn’t find it as fulfilling as I’d hoped,” Honnold has written about an all-day solo link-up of three difficult routes. “People might expect these kinds of climbing achievements to generate euphoria, but in fact I seem to experience the opposite.”

The total lack of activation throughout most of

Honnold’s brain during the reward task is a good fit with the hypothesis that sensation seekers need powerful stimuli in order to ramp up the dopamine circuitry that make an experience feel rewarding, Joseph says. One result can be the endless pursuit of strong sensations, which in the case of substance abuse and gambling, contributes to addiction and dependency.

Honnold could, in that sense, be “addicted to climbing,” Joseph says, and the hunger for sensation could push him ever closer to his limits as a free soloist. At the same time, a defining quality of his ropeless climbing has been the conscientiousness and premeditation that he brings to it. The greatest risk for Honnold, Joseph says, may lie in the tension between those opposing compulsions.

Joseph had expected Honnold to survey low in impulsivity traits, such as urgency and disinhibition, associated with rash decisions and actions taken without much thought to the consequences, particularly when a person is feeling down. In fact, he scored on the high end. This helps explain what might be called, using Honnold’s own terminology, his “fuck it” ascents, in which composure gives way to depression and angst, and planning to, well, impulsivity.

Here’s one: While “emotionally unhinged,” as he put it, by a faltering relationship in 2010, he soloed a 1,000-foot wall in the Nevada desert that he had climbed with a rope only once before, several years earlier. Honnold considers that climb an example of how he has learned to harness both positive and negative moods to achieve his goals. Obviously, it worked out fine—he is still around to tell the tale. But when I ask Joseph if she has any warning to offer Honnold based on the scan and survey results, she replies, “Don’t let the impulsivity win out over the conscientiousness.”

THE NEXT TIME I catch up with Honnold, he’s climbing with his girlfriend in Europe. I want to know if his new awareness of his atypical brain has affected his sense of self. No, he says, the discovery that his amygdala sleeps in his brain like an old dog in an Irish pub has not changed the way he climbs, nor shaken his sense of identity. That isn’t to say that it hasn’t given him pause for reflection.

On a recent rest day from climbing, he says, he and McCandless decided to try a “*via ferrata*” near

Lauterbrunnen, Switzerland. A *via ferrata* is a kind of climbing route with artificial holds: rungs, pegs, ladders, and bridges are attached to the rock, while the climber is protected by a harness connected to a fixed cable. Honnold, of course, didn't bother with the harness.

"But then at a certain point, I was like, actually, this is kind of hardcore. Like I actually needed to pay attention," he says. The *via ferrata*, it turned out, climbed across a sheer rock wall on a series of rebar rungs set 3,000 feet off the valley floor. They were high in the mountains, the weather threatened, McCandless was near tears, and after recent rains, water was streaking down the limestone face and dripping on the hand holds, the foot holds, and their heads.

"I definitely thought about how I process fear," Honnold says. What he realized was that, in this case at least, he didn't. He had been in similar situations so many times that it had become normal. There was nothing to process; there was only who he had become. "This is not scary," he said to himself, "because this is what I do." 🌀

J.B. MACKINNON writes on the environment, outdoors, consumerism, and other topics. His most recent book is *The Once and Future World: Nature As It Was, As It Is, As It Could Be*.

How Woodpeckers Will Save Football

It takes a bird brain to play contact sports safely

BY MOISES VELASQUEZ-MANOFF

IN 2007, **DAVID SMITH**, a doctor of internal medicine and founder of a company that makes wound dressings, gave a presentation at a medical conference in Maryland.

Afterward an audience member, worried by mounting reports of traumatic brain injury from blasts among American soldiers, mentioned, of all things, woodpeckers. If someone could figure out how woodpeckers do it—they slam their beaks into trees thousands of times per day, generating forces far beyond what most people experience in car wrecks—then maybe we could better protect soldiers.

The question sent Smith's own head spinning. "I knew instantaneously that this was something woefully overlooked," Smith said. Nature was full of animals that routinely generated massive forces on their brains without apparent damage. They included big-horn sheep; whales that ram each other; and birds that dive headlong, at 500 feet per second, into the water.

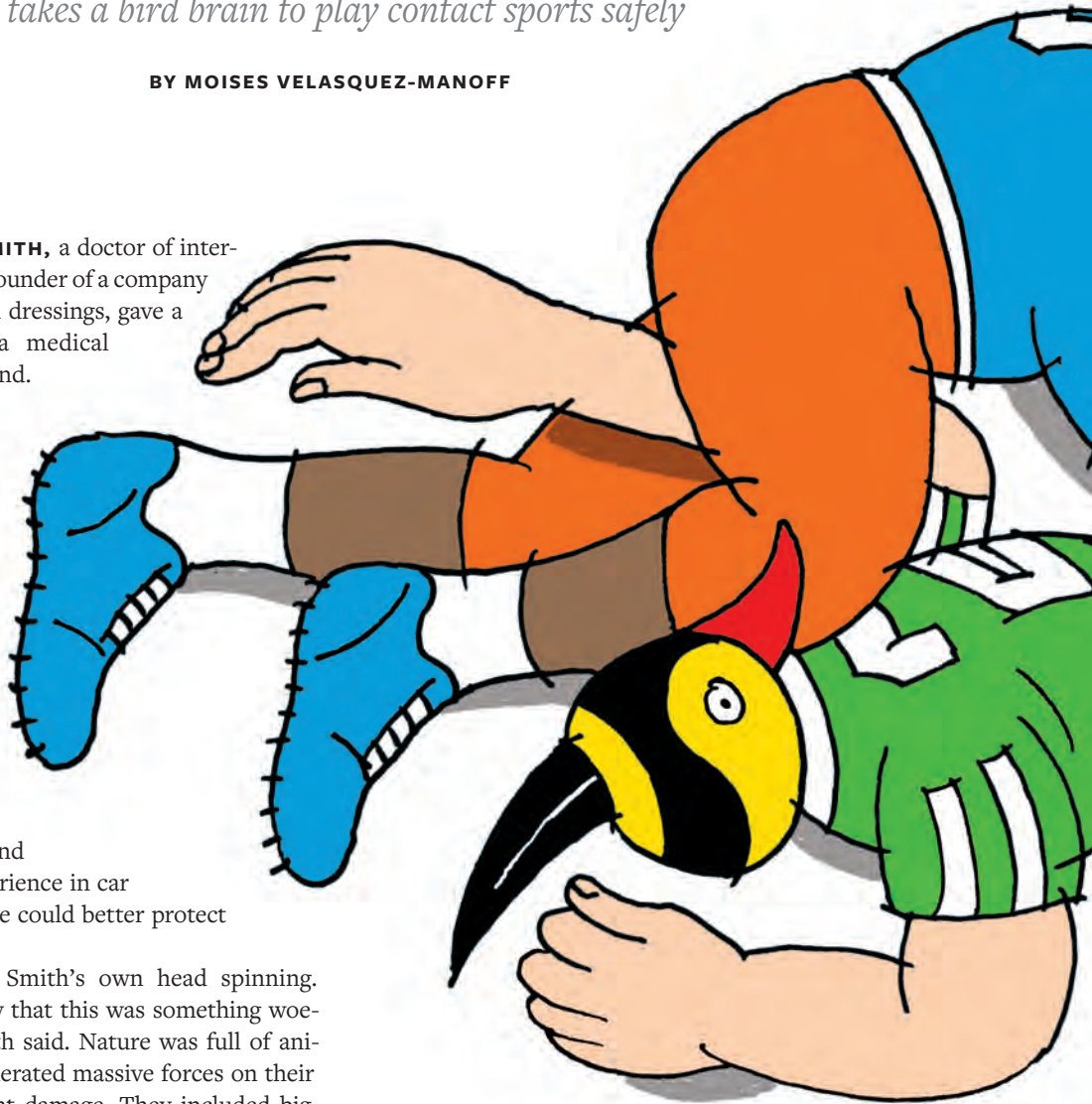


ILLUSTRATION BY SEYMOUR CHWAST

How did the animals avoid brain injury?

The animals' secrets wouldn't apply just to soldiers, Smith knew. Reports were accumulating of a dementia-like syndrome that afflicted former football players, called chronic traumatic encephalopathy. The condition, scientists thought, wasn't necessarily caused by full-blown concussions—the kind that knock you out—but by repeated lighter blows over a long period of time.

The problem is the human head isn't "designed" to take repeated hits. The brain floats in fluid slightly removed from the skull. But because it's not the same density as the fluid around it—and even the different tissues within the brain aren't of equal density—when you collide with another player, the brain moves through the surrounding fluid, smashing and deforming against the skull. That slosh, or "rattle," as some call it, compresses and shears neurons, injuring them. Something called cavitation may also occur: the formation of gas bubbles driven by a rapid change in fluid pressure. When you're hit on the football field, in other words, parts of your brain may fizz like a just-opened can of soda.

Smith had an eclectic background: He had an M.D., math skills, and a degree in chemistry. His company's wound-care products accelerated healing by maintaining moisture at the wound site. He also loved football. He played in high school, and swam competitively. So he dove into the literature on woodpecker physiology, trying to discern how the animal protected itself.

He immediately fixated on an unusual feature of the woodpecker's physiology: its long tongue, which wraps underneath and up and around the back of its skull. A muscle that rests against the animal's jugular veins moves the tongue. So the woodpecker could, in theory, use its omohyoid muscle, as it's called, to constrict these veins, reducing the outflow of blood from its skull.



When you're hit on the football field, your brain may fizz like a just-opened can of soda.

This was, Smith thought, the woodpecker's secret. It likely clinched its jugular vein with its long omohyoid muscle, protecting against brain slosh by filling its brain with blood.

Smith wondered how he could replicate this in people. One possibility was to elevate carbon dioxide. We produce CO₂ during regular cellular processes, and expel it when we exhale. But if blood CO₂ goes too high, indicating an oxygen-poor environment, blood flow to the brain increases to ensure that the all-important organ has sufficient oxygen. That meant one way to swell the brain was to increase blood CO₂.

In fact, Smith suspected that woodpeckers and many other birds did this as well—they could deliberately elevate blood CO₂. Birds have a unique respiratory system which, in addition to lungs, features air sacs distributed throughout their bodies. The sacs are connected via birds' hollow, "pneumatic" bones. Smith thought that maybe this extended respiratory system allowed some birds to "re-breathe"—to re-inhale off-gassed CO₂—increasing carbon dioxide on demand, boosting the blood volume of their brains, and protecting their brains during the many collisions of avian life.

Smith needed evidence this might apply in people. So he teamed up with Gregory Myer, director of research in sports medicine at Cincinnati Children's

Hospital Medical Center. (Today Smith is a visiting research scientist at the center.) The CO₂ hypothesis afforded a prediction. High altitude changes the ratio of carbon dioxide to oxygen in the blood, producing a slight swelling of the brain. (At really high altitudes, the swelling can lead to the dizziness and vomiting of altitude sickness.) Would this mild, altitude-induced "edema" protect people from head injury?

Myer and his colleagues looked at a database of NFL games played around the country. Games played above 644 feet, they found, reported 30 percent fewer concussions than games played at lower altitudes. The thinner air—or perhaps the body's adaptive response to lower oxygen—seemed to protect players' brains.

Smith has a knack for getting scientists on board with his ideas even if, at first blush, they're not sure if he's crazy or a genius. Ultimately it was another research scientist named Joseph Fisher who devised a more practical way to mimic the woodpecker. Fisher, a professor at the University of Toronto, studies how gases diffuse in the blood, particularly carbon dioxide. He agreed to hear out Smith, formaldehyde-soaked woodpecker in tow, over dinner. "He had no data, but he had a brilliant insight," Fisher said.

Fisher didn't think Smith's initial approach was right, though. He wanted to raise people's CO₂

artificially, induce mild brain swelling, and protect against trauma that way. But high blood CO₂ would be uncomfortable, Fisher thought, leaving people feeling as if they were suffocating and gasping for air.

Fisher, an anesthesiologist by training, thought a second approach, one more in line with the woodpecker's omohyoid solution, made more sense. He knew from personal experience that just a little pressure on a person's neck would make the brain swell. He'd seen it happen. Brain surgeons sometimes complained that the brain swelled up during surgery, so they dispatched Fisher to find out what was crimping their patients' necks. (The problem might be that the patient's head was slightly turned, applying pressure to the jugular veins.)

So forget CO₂, Fisher thought. All you needed was to press lightly on the neck. Fisher bought a pair of headphones at an electronics store, bent the metal band a little, and placed them around his neck with the pads against his jugular veins. He felt his face flush. An avid cyclist, Fisher would wear that jerry-rigged collar for the next two years while biking.

Not everyone agrees with Smith's basic scientific premise. Andrew Farke, a scientist at the Raymond M. Alf Museum of Paleontology in Claremont, California, who studies head-butting animals, said no one has looked into the question of whether woodpeckers and rams really bang their heads without hurting their brains. It's widely assumed these animals don't have problems from a lifetime of head-smashing, he noted, but it's not proven. Maybe woodpeckers or rams don't live long enough in the wild to develop degenerative conditions like CTE. "The stereotype that they're not suffering any ill consequences is probably something that should be evaluated," he said.

And about the CO₂ hypothesis. Smith thinks that bighorn sheep, which slam into each other at 40 miles per hour, generating up to 500 Gs of force, "rebreath" through their hollow horns, raise their blood CO₂, increase the blood volume in heads, and protect their brains during those fearsome collisions. But the animals' hollow horns are nearly impossible to breathe through, Farke said. The purpose of the hollows, he said, is to create distance between the area of impact and the brain. And the horns themselves help diffuse force. They're sheathed in the same stuff that hair is



THE DICK BUTKUS OF BIRDS Woodpeckers may not damage their brains by banging their heads like legendary linebackers, thanks to their unique anatomy.

made of—keratin—and they flex slightly during collisions, "like a crumple zone on a car," Farke said.

Farke added that woodpeckers' unique wrap-around tongues can press on their jugulars. But the birds also have many other adaptations, including shock-absorbing areas of the beak and body. "It's very rarely a single magic bullet," Farke said. "As with pretty much everything, it's a whole bunch of adaptations."

And yet a rodent study conducted by Julian Bailes, a concussion expert and chairman of the department of neurosurgery at the North Shore University Health System in Evanston, Illinois, stunned everyone with its results. Rats that wore a collar-like apparatus



A RUSH OF BLOOD TO THE HEAD In a field test, high school football players wore an experimental neck band, which squeezes veins, sends blood to the head, and may protect against destructive brain slosh.

around their necks that lightly compressed their jugular veins while they were knocked on the head saw an 83 percent reduction in brain damage compared to rats that didn't. "I was dumbfounded," Fisher said of the results. "I would have been happy to have 10 percent improvement."

Football helmets were originally designed to prevent skull fractures, which they do fairly well. But to preclude movement *inside* the skull, helmets would have to significantly slow down the period of impact. A helmet able to achieve this feat might look like a giant, fluffy marshmallow—unwieldy, and perhaps ergonomically impossible to wear. Myer, for one, thinks that a helmet, no matter how well designed, is unlikely to prevent CTE in sports like football. "Our brain already has a helmet, it's called a skull," he said. "Why put another shell on the skull? You're just adding mass."

Smith enlisted a sportswear company now called Q30 Innovations to design a collar for human use. The device they've come up with is made of light, springy metal coated in a plastic polymer. It's C-shaped, slides over the back of the neck, and leaves the windpipe untouched. The collar increases blood in the brain by about a teaspoon. That's equivalent to the extra blood that pools in your head when you lie down. Or when you yawn. "If you think this is dangerous physiology, for God's sake, don't yawn," Smith said.

To test the collar in people, the scientists couldn't very well knock people repeatedly in the head deliberately. So Myer turned to two high school football teams in Cincinnati. The players agreed to have an array of sensors placed in their helmets, allowing the scientists to see, after games, how many collisions the players had experienced, and at what force. In one game, Elijah

“Our brain already has a helmet, it’s called a skull. Why put another shell on the skull?”

Payne, a 225-pound middle linebacker at St. Xavier High School, registered 31 hits, some of them 20 times the force of gravity.

The collar took some getting used to, Payne said, particularly on hot days during intense practice. He could feel the pressure on his neck. Once when he was running sprints, he almost took it off. “I’d be lying if I said it wasn’t tough,” he said. But Payne persevered, and with time he stopped noticing the collar at all. By the end of the season, it had become just another piece of football equipment.

Before and after the season, Payne and his classmates underwent a type of brain scan called diffusion tensor imaging, which measures changes in the brain indicative of damage. By season’s end, each player had experienced, on average, about 800 head impacts greater than 20 Gs. And when Myer compared scans from before and after, he noted changes in the brains of kids who hadn’t worn the collar—evidence of damage. The kids who had worn the collar, on the other hand, saw significantly fewer changes. Their brains hadn’t suffered the same way. The findings were also replicated in hockey players. What worked for woodpeckers seemed to work for humans. A little extra blood in the skull swaddled the brain enough to reduce damage.

The studies have some weaknesses. There’s no

placebo group, no players wearing a collar that does nothing—something that’s hard to do in these kinds of studies, Myer said. And no one knows if the reduced damage seen in the collar-wearing group, as measured by diffuse tensor imaging, will translate to a lower risk of CTE later. So far, CTE can only be diagnosed after death.

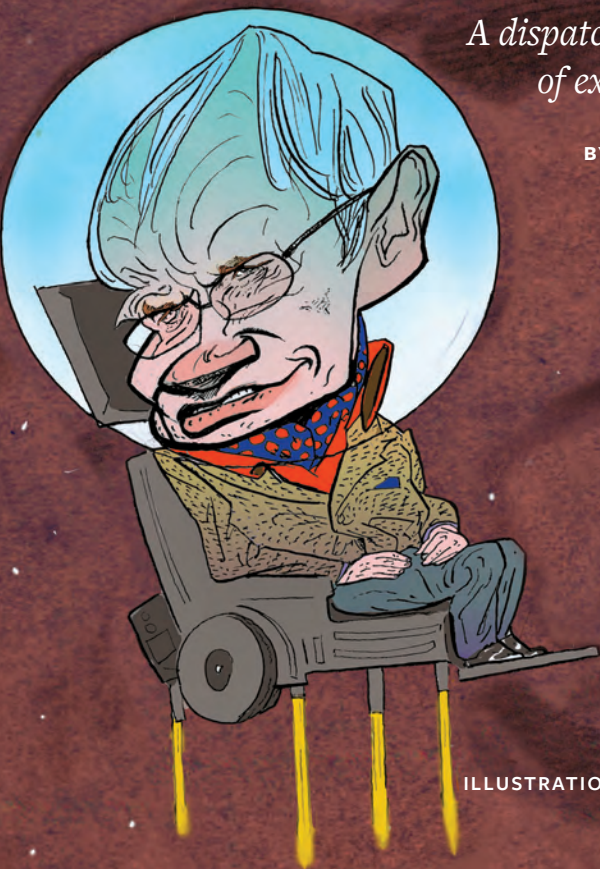
Still, what began years ago as one man’s obsession with woodpeckers may soon yield a commercial product that protects your brain by gently squeezing your neck. Q30 Innovations, and another company, Performance Sports Group, are trying to gain FDA approval to sell the collar as a medical device. Smith, who’s 57 and owns a patent for the collar, is about to leave medicine to focus on a line of research that began with an obsessive foray into woodpecker physiology. “I really feared for the future of football,” he said. “I actually don’t anymore. I think we can prevent CTE.” 🌀

MOISES VELASQUEZ-MANOFF is a journalist and author of *An Epidemic of Absence: A New Way of Understanding Allergies and Autoimmune Diseases*.

When the Olympics Go Intergalactic

*A dispatch from the future
of extreme sports*

BY CHIP ROWE



ILLUSTRATIONS BY STEVE BRODNER

BACK IN THE DAY, before the speed of light was considered the slow lane, “extreme” sports—bungee jumping from bridges, hang gliding over volcanoes—were barely deadly and almost quaint. But with the advent of hyperflight, adventure sports are undergoing a revolution. Thrill seekers are now testing boundaries far beyond Earth’s atmosphere: scaling mountains on Mars, surfing powerful stellar gas

jets, and playing chicken with black holes.

Profiting handsomely from all this action is Jimmy Doogle, founder of the Extraterrestrial Sports and Programming Network (ETSPN). “Thank God for the spacetime continuum,” he says with a laugh, during which he earned another trillion dollars. *Nautilus* recently caught up with Doogle to find out what today’s adrenaline junkies do for a fix.

Black-Hole Diving

According to Einstein's theory of relativity, nothing escapes a black hole. So a diver's goal is to get as close as possible to the point just before the point of no return. It's a calculated risk. It's not yet clear, for instance, how this invisible boundary, which may be in constant flux, should be marked. So there's no way to know you've crossed it until it's too late.

To date, 27 daredevils have taken the leap. But because no one has yet returned, no record has been established. Nevertheless, there's plenty of optimism back at the Bungee Hole Space Center near black hole AO620-00, in the constellation Monoceros, where support teams are camped out. On the wall over the bar, where robotic arms serve cocktail capsules,

27 stopwatches tick away. The longest-running clock, timing presumed leader Buck "Rogers" Ruttle, reads 61 Earth years.

However, diehard fans remain hopeful. Even if black holes swallow every last diver, they point out, a centuries-old assertion by immortality pioneer Stephen Hawking, if true, may assure their heroes still receive their due fame. According to Hawking's calculations, black holes "leak" matter in the form of radiation and particles, and eventually explode, spewing everything they consumed. That's why divers can always find sponsors. Even a smidgen of DNA rocketing back into ordinary spacetime would trigger thousands of branding deals.

Flaming Ice Hockey

Modern athletes pride themselves in their ability to withstand boiling temperatures and frozen terrain. But it wasn't until explorers mapped the planet Gliese 436b that competitors got the chance to tackle both extremes at once. Roughly the size of Neptune, Gliese orbits far closer to its sun than Mercury does to ours, making its surface a balmy 820 degrees Fahrenheit. At that temperature, you'd think the planet would be all gas. In fact, immense pressure in Gliese's interior compresses water into an exotic phase of ice known as Ice X, in much the way pressure in Earth's interior turns carbon into diamond.

The result is a world cloaked in "hot ice" and bathed in steam. A decade ago, 10 tenacious hockey teams flew the 30 light-years to Gliese for the first of what has become an annual tournament. The flaming

puck makes the action easy to follow. Traditionalists grumble that players hop instead of glide, but there's not much to be done about that: Unlike ice on Earth, Ice X isn't slippery. The molecules at its surface are under such great pressure that friction from a skate won't soften the top layer of ice enough to allow the skate to slide smoothly across it.

Recently, Gliese's hard-core conditions have begun attracting other athletes looking for an edge. Nordic explorers, deeply discouraged by the last piece of ice melting at the North Pole, are some of the newest arrivals. And when you tune into a hot ice hockey game on ETSPN, Doogle says, keep an eye on the arena between periods: You might just catch a figure skater emerging from the mist, skintight asbestos costume aflame.

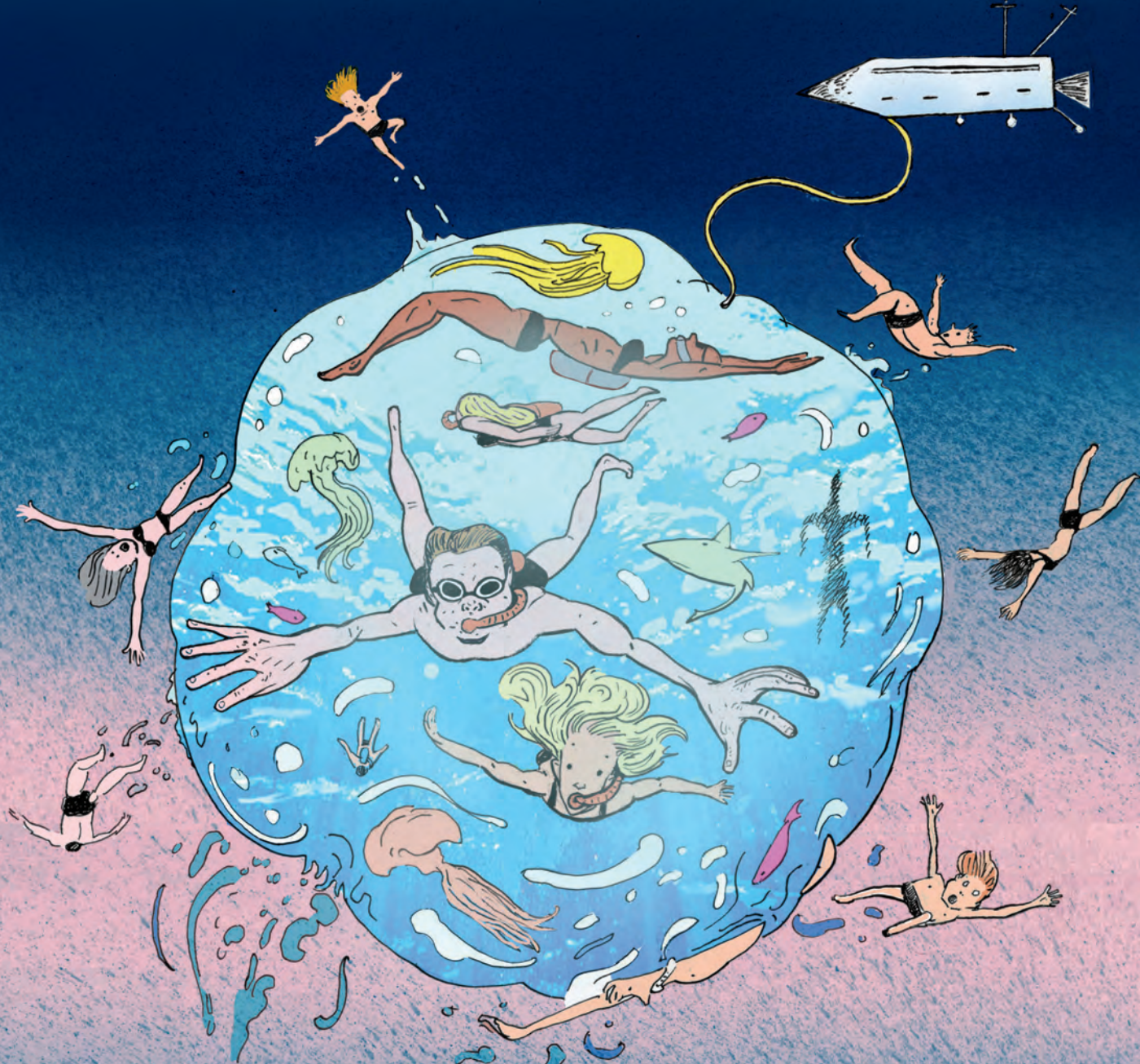


Nebula Gas Surfing

The coolest natural spot known is the Boomerang Nebula, where the temperature is just 1 degree above absolute zero (−459 degrees Fahrenheit). The nebula was born when a star in the constellation Centaurus began dying, a process that causes it to expel gas from its core. The gas gushes so fast—10 times faster than in a typical nebula—that it expands. And as it expands, it gets extremely cold, much like when air spews out of a tire nozzle. Even empty space, bathed in radiation from the Big Bang, is warmer.

But Boomerang’s gelid climate doesn’t seem to bother the wind surfers who travel 5,000 light-years to ride its “rad” 100-mile-per-second gas stream. “Any paddlepuss can surf on bonded hydrogen and oxygen,” one veteran scoffs. The only downside of this “chill ride,” she says, is when the gnarly nebular winds peter out and you find yourself 100,000 miles away from the launch site, disoriented and alone, floating aimlessly in the darkness until you can get enough bars on your hologram phone to call an Uber.





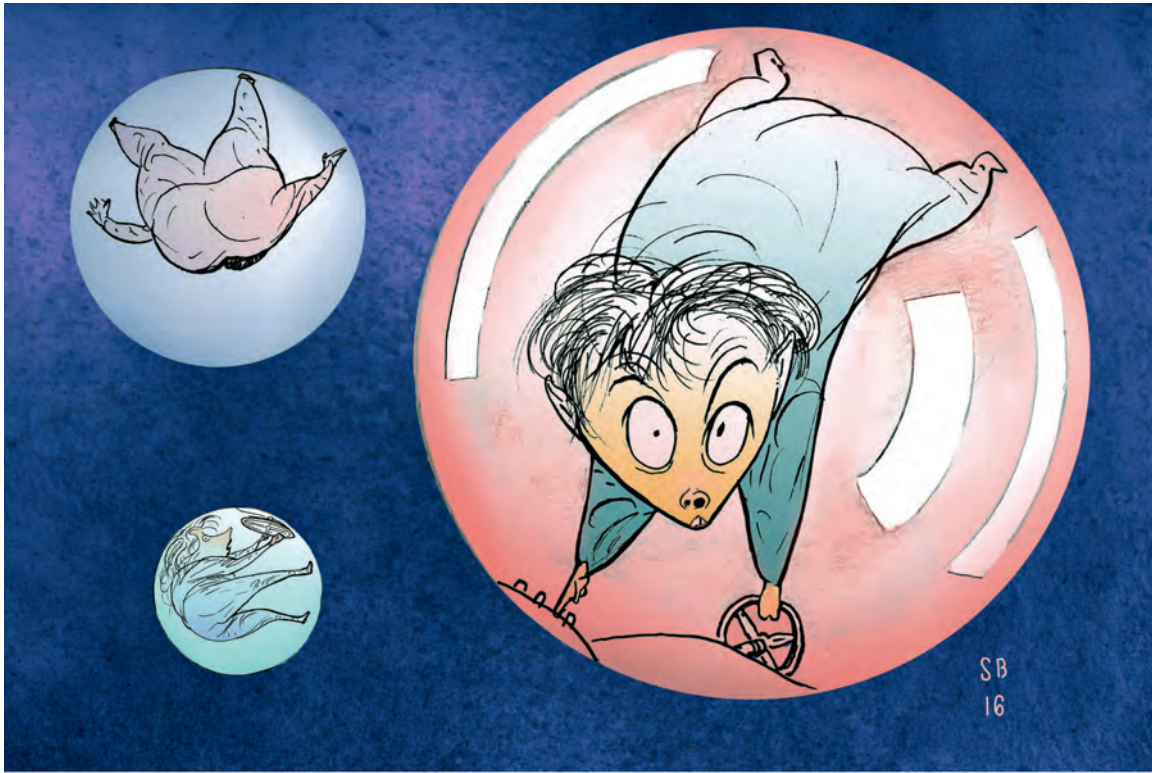
Zero-G Swimming

In a 1994 paper in *Proceedings of Space*, Japanese scientists rightly predicted that a major obstacle to space pools would be rocketing hundreds of tons of water into the void. After countless hauls, and several rounds of fundraising, the space hotel industry finally opened the first Zero-G water park—only to be sued by the survivors of the first eager swimmers: Without gravity, there was no obvious way to find the “surface” of the 85,000-gallon floating blob. But engineers quickly found a fix. By spinning the blob, they could induce just enough gravity to create “up” and “down.”

Guests were happy enough. But the development

made endurance swimmers, who were running out of new Earthbound challenges, drool. Much to their embarrassment, however, the pioneer of intergalactic water sports turned out to be a stoned teenager named Greco Roman, who, while vacationing with his family at a space casino, broke into its pool to swim in the endlessly rotating lap lane. Still at it two days later, he inadvertently set the first Guinness World Record for space swimming. Professional swimmers flocked to space pools to beat it. It wasn't long before they were clandestinely importing sharks and jellyfish “to make things more interesting.”

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The Draco 1000

After ticket sales among millennials, the first generation to grow up with intergalactic travel, plummeted at the annual Baja 1000 off-road race in Baja California, Mexico organizers announced a new location: the planet TrES-2b. About 750 light-years east of Mexico in the Draco constellation, the gas giant is billed as “the darkest place in the universe.” Reflecting only 1 percent of the light that strikes its surface, it is, in fact, blacker than coal.

Like hamsters in plastic balls, Draco 1000 racers propel insulated space orbs, many of them made by welding together decommissioned NASA parts. To navigate the course, pilots rely on instrument panels, Google Galaxy, and whatever they can make out in

the red glow of the planet’s 1,800-degree surface. Like barefoot devotees walking over glowing embers, they are advised to keep moving.

Due to TrES-2b’s low reflectivity, the race is impossible to broadcast from overhead, Doogle says. But ETSPN has created a hit show with dash cams, satellite trackers, and open communication channels between the grizzled contestants, most of whom have been banned from driving elsewhere. The seat-of-the-pants navigation adds to the drama. In one infamous incident, a pilot bought what he thought was a rare terrain map on eBay Mars only to discover mid race that he was looking at downtown Pittsburgh.



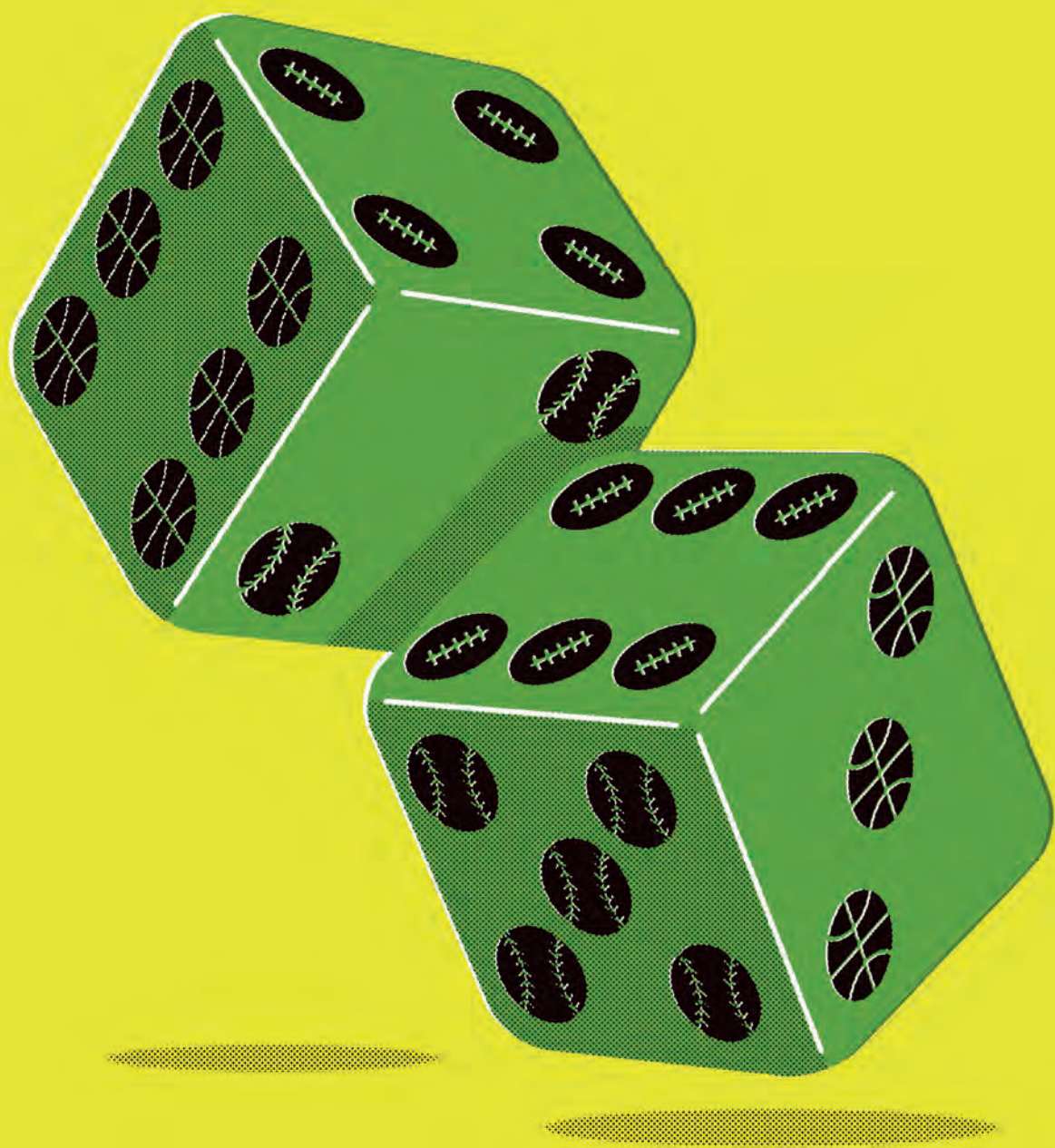
The Next Seven Summits

It used to be a big deal, back when your great-great-great-grandparents' heads were still attached to their original bodies, to scale the highest peak on each of Earth's seven continents. But after the feat had been accomplished more than 1,000 times, including by an infant who learned to walk on the way down, dopamine-addicted climbers turned to the "next seven," a circuit of some of the highest and most treacherous peaks in the Solar System.

The protective suits needed to bag peaks 8 through 14 may be cumbersome. But what you lose in mobility, you gain in lightness. After summiting Mons Huygens on Earth's moon, which most climbers dismiss as a training run (and which

is currently closed to clear the litter), mountaineers head to Mars for Olympus Mons, whose peak towers nearly 17 miles above its base. (By comparison, Everest's base-to-peak length is about 2.3 miles.) Other mountains on the tour include Venus's 4-mile-high Skadi Mons, whose slopes are covered in lead sulfide "snow"; Rheasilvia, which rises 14 miles from the center of an impact crater on the asteroid Vesta; and Norgay Montes, an ice peak looming 2 miles over the surface of Pluto. ☺

CHIP ROWE is a writer based in New York who rode a skateboard once in the fourth grade.



Are Fantasy Sports Really Gambling?

Fantasy sports are more skill-based than real ones, changing how the multi-billion dollar industry will be regulated

BY NIKHIL SWAMINATHAN

EARLY ONE SATURDAY MORNING in Las Vegas, I sat down at a Texas Hold ‘em poker table with seven or eight other men, all middle-aged. Being 30 at the time, I was the youngest player by about a decade. A couple of them were wearing Hawaiian shirts. It was too early for drinking, but one or two guys puffed on cigarettes as the cards were dealt. The buy-in was \$75, far more than I’d ever paid for a poker game.

I played in a regular poker game in New York City, and I was feeling good about my abilities. I decided to use a conservative strategy to extend my time on the table: Only stay in a hand when I have cards worth playing. In retrospect, I was probably primed to be taken down a notch or two.

My plan quickly proved worthless. The luck of the cards wasn’t with me. My best hand was maybe a Jack High. Worse, the others at the table were betting aggressively and bluffing masterfully. Well, I assumed they were bluffing. I think I actually saw a player’s winning cards only once. I swiftly suffered the fate of fools

with money. My opponents cleaned me out in five or six rounds. Poof! My 75 bucks were gone.

I gained very little from that experience—both financially and as a way to pass time. But I did learn one thing: I would have been better off if the game had involved less skill and more chance.

Coincidentally, laws in the United States tend to have the opposite opinion, and favor skill over chance. They regulate games of chance differently (and more strictly) than games of skill, and regard the former as gambling. Of course, both chance and skill play a role in nearly every contest, from poker to pingpong. But in the eyes of the law, it is more acceptable to participate in a game of skill, where those with knowledge, experience, or talent are more likely to prevail, than in a game of chance, where all players have the same odds.

In 2006, the U.S. Congress passed the Unlawful Internet Gambling Enforcement Act (UIGEA), which prohibited gambling enterprises from processing payments online from U.S. credit cards and banks. That law effectively crippled the sizeable online poker

industry in America (for a sense of scale, the industry brought in an estimated \$2 billion in 2005 worldwide). Now, authorities in states across the country have turned their sites to another target: the daily fantasy sports industry. Fantasy sports, in the ensuing effort to show that they are based more on skill than on chance, have in some ways succeeded far beyond their intention—they are, in many cases, more skill-based than the real sports on which fantasy players are betting.

Which is probably good news for them, as regards regulation. But where does that leave players like me?



FANTASY SPORTS SITES DraftKings and FanDuel let contestants enter for as little as \$1, or for several thousand dollars. Contests are available in each of the four major U.S. sports leagues: Major League Baseball, the National Basketball Association, the National Football League, and the National Hockey League. Contestants choose a lineup of players in a particular sport with a limited fund of money, known as a “salary cap,” and can find out if they’re a winner as soon as the evening’s games are over.

In the case of fantasy baseball on FanDuel, for instance, contestants select a nine-player team consisting of a pitcher, catcher, and all the infield and outfield positions. Contestants can’t simply pick a roster of superstars. Each available player is assigned a salary for the day by FanDuel. Contestants must select a roster of players whose combined salaries add up to \$35,000 hypothetical dollars or less. Ace pitchers can cost in the low-five figures, while elite batters usually run over \$4,000, meaning it’s nearly impossible to stack a team with standout players. Points are accrued based on how those players do in games played that day. The challenge for contestants is to choose the nine players who will provide the most points, while staying within the salary cap. So, essentially, the skill needed to excel in daily fantasy sports is bargain hunting.

Some of the networks that carry sporting events hold large stakes in the daily fantasy portals. Those sites, in turn, buy advertising. DraftKings recently struck a deal with ESPN to buy \$250 million in ads over the next two years. The sporting leagues also

have lucrative marketing deals with them. In late 2014, the NBA entered an exclusive marketing sponsorship with FanDuel and bought an equity stake in the site, which is currently the industry’s leader. The startups make money by taking in entry fees for the hundreds of contests they offer daily. They return the bulk of that money as prizes to winners, keeping about 10 percent of what’s anteed. Last year, players anteed up \$3 billion in entry fees on DraftKings and FanDuel. Together, the websites hauled in just short of \$300 million in revenue, nearly three times what they took in back in 2014.

But an incident in late September of 2015 that some saw as tantamount to insider trading attracted unwanted attention to the industry. A DraftKings employee, Ethan Haskell, reportedly accidentally published a blog on the site data on which football players were the most rostered ahead of the third week of the NFL season. The fantasy sites set prices at the beginning of a contest, and they don’t change before users have to lock in their rosters, just as the real-life games start. By knowing who was on other fantasy team lineups, contestants might have noticed undervalued players chosen by their peers that they would have passed over otherwise. Worse, it soon became clear that employees of either site, while banned from playing on the portal where they worked, were using this information to win thousands of dollars on their competitor’s platform. Haskell, for instance, won \$350,000 in a contest on FanDuel the same week he leaked the data.

DraftKings and FanDuel quickly forbade their employees from playing daily fantasy contests, but Pandora’s box was open. Nevada quickly deemed that DraftKings and FanDuel were hosting gambling and asked the companies to secure licenses. And in November, after an investigation into the industry, New York State Attorney General Eric Schneiderman ordered the web sites to cease operations in the Empire State. New York was home to, according to an affidavit submitted by DraftKings Chief Financial Officer Tim Dent, more than 5 percent of its users and 7 percent of its entry fees in the first 10 months of 2014.

Playing online fantasy sports for money was already banned in Arizona, Iowa, Louisiana, Montana, and Washington state when DraftKings and FanDuel launched in 2012 and 2009, respectively. But since the

Real-life versions of sports involved less skill than their fantasy corollaries.

Haskell incident, Alabama, Illinois, and Texas are also taking action against the sites.



IN A PRESCIENT MOVE in January 2015, FanDuel approached Anette Hosoi, a professor of mechanical engineering and mathematics at the Massachusetts Institute of Technology, and asked her if she'd analyze the results of daily fantasy contest entries put in by between half a million and a million players to see if their offerings were more games of skill or of chance. Hosoi is an avid mountain biker and snowboarder, and in the fall, she plays season-long fantasy football. And in 2012, she founded the Sports, Technology and Education @ MIT (STE@M) program.

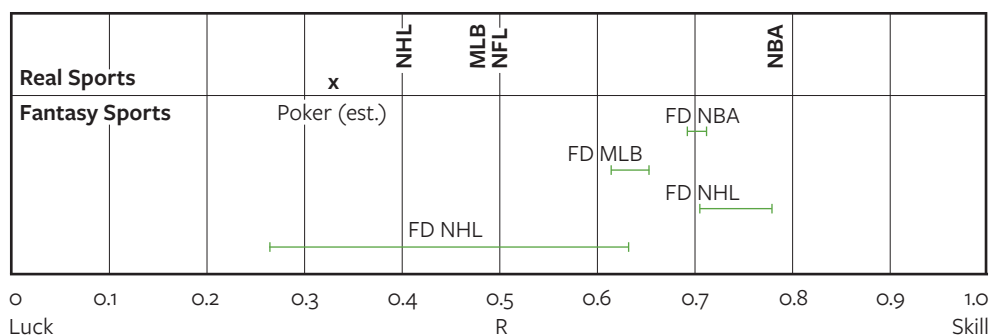
Many of STE@M's projects are mechanical in nature—redesigning hockey sleds used by Paralympic athletes or determining the optimal strategy for team pursuit cycling races. But the FanDuel project allowed Hosoi to investigate a dataset for insight as to the role of chance in the way fantasy contests are currently designed. “It’s such a great mathematical problem,” Hosoi says. “Someone gives you a pile of data, and you see if you can figure out if it arose by chance.”

A self-described visual learner, Hosoi immediately

began plotting the data. First she compared the performance of FanDuel players to that of lineups that were randomly constructed by computer simulation. If the fantasy contests were largely chance-based, over hundreds of games the simulated lineups should score as well as the human-chosen ones. But real rosters significantly outscored the random ones. When Hosoi tweaked the algorithm to make the simulated lineups more realistic (for instance, ensuring that more money was set aside for quarterbacks than kickers in football games), the human-picked teams still overwhelmingly netted more points.

Hosoi also developed a metric for measuring the relative skill involved in any contest based solely on players' outcomes. She began by plotting the results of FanDuel players on a graph where the x-axis was a player's win percentage in the first half of a season, while the y-axis was the win fraction in the second. In a purely chance-driven contest, one would expect a symmetrical distribution around 50 percent on both axes, right at the center of the graph, since the odds of success are even. In a skill-based game, however, there will be a distribution of outcomes, which Hosoi says indicates multiple skill levels. Poor players fall at the lower left of the array; elite ones find themselves on the top right of the array.

In a perfectly skill-based competition, plotting the



WHICH SPORT IS LUCKIEST? Anette Hosoi calculated where various sports fall on a continuum from entirely luck-based to entirely skill-based. The higher the *R*-value, the more skill dominates. On the chart, “FD” indicates that the data came from Fan Duel. Hosoi found that the outcomes of NBA basketball games were the most dependent on skill. Comparatively more randomness is inherent in the outcomes of professional hockey, football, or baseball games. Poker, according to Hosoi, is the most luck-influenced.

results of each contest would create a diagonal line in the middle of the graph. The farther off that line the array is, the more chance is inherent in a contest. This distance can be translated into a skill-factor value that Hosoi calls “*R*.” The higher *R* is, the more skill is involved. “The *R* value is totally independent of the rules of the game,” says Hosoi. “All you have to do is give it the set of outcomes. So I can apply it to real sports, blackjack, anything you want.”

When Hosoi compared the *R* values of FanDuel contests to actual professional sports teams, she found that the outcomes of real-life sports involved less skill and more randomness than their fantasy corollaries (with the exception of basketball, whose many opportunities to score reduce its randomness). In fantasy hockey, skilled contestants will succeed slightly more often than elite NHL teams will. In a real-world hockey game, a weird puck bounce can lead to a fluke goal. Because hockey games are relatively low-scoring, moments of randomness can have an outsized impact on the outcome of a matchup. To a lesser extent, the same is true in baseball and football, both games where scoring opportunities can be hard to come by.

It’s weird to think that honing one’s ability to spot value when assembling fake rosters of professional athletes can ensure someone a higher likelihood of success, as measured by victories, than spending years working on hitting a baseball or shooting a three-

pointer. (Of course, being an elite professional athlete will earn you a lot more money.) But the best daily fantasy players do have a well-defined set of skills, which they hone over thousands of hours of practice. Chief among these: an acute attention to detail.

Peter Jennings is best known as the winner of DraftKings’ Legends Series Fantasy Baseball Championship in 2014, where he outscored other elite daily fantasy players in 50 contests over five days at a resort in the Bahamas to claim a \$1 million payout. Jennings, who is 28 years old and lives just south of Denver, quit his job as a stockbroker in 2012 and now makes his living playing daily fantasy games, pulling in six figures yearly.

Jennings enters thousands of contests per day, sometimes submitting just one or two optimized lineups per sport. He spends 80 to 85 hours a week researching and playing fantasy sports. He watches hundreds of games to assess some of their more subjective aspects, like how well offensive lines block in football or if a basketball player sustains a minor injury that might impact his play.

Even if he’s not watching film, he’s still weighing dozens of factors through custom mathematical models he’s developed to assemble what he thinks will be an optimal high-scoring lineup each day. “In a sport like baseball, there’s so much data,” he said. “I know a lot of successful [fantasy sports players] that don’t watch baseball.”

According to an affidavit he supplied on behalf of DraftKings for its New York State legal proceeding, in baseball, he accounts for batted ball speed (a measure of whether a hitter is making good contact), weather forecasts, air density (which impacts how far a hit ball might travel), which umpire is calling balls and strikes, and even player psychology—like if a pitcher is trying to bounce back from a humiliating outing.

But, as good as he is, Jennings cannot rely solely on his data-mining. He also needs the betting site to leave something on the table when it sets prices.



IN A STATEMENT SENT TO NAUTILUS, FanDuel explained that it sets players' prices "by analyzing different data points and statistics (generally on a daily basis) in order to make projections regarding fantasy performance. At the beginning of each season, we price each active player. We then change prices daily,

or weekly for NFL, based on factors such as individual performance, team performance, opposing team's defense and ability and historical ownership percentages." But they could do better.

Fantasy experts like Jennings exploit inaccuracies in how FanDuel and DraftKings price players, looking for athletes who are likely to produce a lot of return but don't cost much. Prices aren't perfectly predictive of how a player might perform, or changed based on the popularity of a player among other fantasy players. They are also set up to 24 hours in advance of games, so that news regarding weather, injuries, lineup changes, and so on can make prices inappropriate by the time the first pitch is thrown.

According to University of Chicago economist Steven Levitt of *Freakonomics* fame, the daily fantasy portals could stymie Jennings and his fellow elite contestants by adjusting the prices they put on athletes so they rise with demand. Improving their algorithm until they hit on, essentially, the perfect model for accurately predicting which athletes would perform well on



Keeping Up With the Jenningses

Peter Jennings is one of the world's best fantasy sports players, but it's not just the computer algorithms he uses to choose players that give him an advantage over a casual player like me. Jennings also thinks differently about sports than I do—and thinks more about them.

Over the course of mid-May and early-June, I assembled FanDuel lineups for 30 different 50/50 fantasy baseball contests, where the top 50 percent of entries all win payouts equal to 80 percent more than the entry fee.

Because I'm an experienced season-long fantasy sports player, I felt I needed at least a baseline amount of knowledge to have a chance of winning the daily contests. I was dependent on ESPN's "Hitter matchup ratings," a free advice tool that indicates how the left-handed and right-handed batters on a particular team were likely to perform against the pitcher they faced that night. For pitching, I tried to save money by finding a less-than-elite hurler facing a crappy team. (This season, my beloved Atlanta Braves qualifies as one of those squads.) That way, I could invest in multiple hitters capable of doing damage, even if a few carried high price tags.

When I spoke to Jennings after I'd played my FanDuel contests, we had

a given day, and then pricing them accordingly, would eliminate the inefficiencies exploited by the elites.

"The sites could take much of the skill component away," Levitt, who performed an analysis similar to Hosoi's on Texas Hold 'em a couple years ago, wrote in an email. "There would be no bargains." This would have the benefit of making the playing field more even for contestants, and broadening the pool of winners.

According to a study by poker strategist Ed Miller and Daniel Singer, leader in Media and Entertainment Practice with McKinsey & Company, most people who play on DraftKings and FanDuel are lambs being brought to slaughter. In a sample of contests from the first half of the 2015 Major League Baseball season, just 1.3 percent of daily fantasy players won 91 percent of the winnings.

"It's a game of skill in that there is very little opportunity for people to consistently win over time," says Andrew Billings, director of the sports communications program at the University of Alabama and the coauthor of *The Fantasy Sport Industry: Games within Games*. "But they're advertising the exact opposite—that any schmuck from across the street can pick a few players and win a million bucks."

At the same time, showing that more-skilled fantasy players have an advantage over others is key to the fantasy sports industry's survival. To avoid legal headaches, they would be well advised to keep their algorithms vulnerable to exploitation, and keep in place a system where an elite cadre of experts run roughshod over unsuspecting noobs.

The industry needs to negotiate these tradeoffs, explains Hosoi. "That tells me there's some pricing strategy that's going hit that sweet spot, where you're within the definition of skill, but it's still fun for a broad range of people," she says.



FOR THE MOMENT, daily fantasy looks like it will live on in New York. The state senate passed a bill at 2 in the morning on Saturday, June 18, proclaiming DraftKings' and FanDuel's contests games of skill. The bill, which is identical to one passed by the state assembly the day before, moves on to Gov. Andrew Cuomo to

Essentially, the skill needed to excel in daily fantasy sports is bargain hunting.

sign and put into law. But legal experts expect that the challenges to the industry will continue—as will the questions about skill versus chance. The next battleground for the fight is expected to be Illinois.

The New York legislation goes some way toward protecting less-skilled players, by requiring that high-skill and high-volume players are clearly identified on the sites. Abraham Wyner, a professor of statistics at the University of Pennsylvania's Wharton School of Business who wrote an affidavit in support of DraftKings' contests being games of skill, explains that chance can have a greater impact on outcomes when skill levels are well matched. For instance, in an Olympic sprint event, all participants are blazing fast, so a runner's start or the lane they're assigned to could mean the difference between winning and losing. Likewise, it's tough to predict the victor between two chess grandmasters, but the outcome is rarely in doubt when one plays an amateur.

And that gets at the very essence of chance versus skill in contests. Skill-based contests tend to exclude people who cannot succeed—to wit, it's been years since I last played chess. Chance games, on the other hand, pull the floodgates wide open (see, for instance, state lotteries). According to Hosoi's *R*-value analysis, daily fantasy sports are far more skill-involved than, say, Texas Hold 'em, the online version of which is slowly making a comeback in states like New Jersey, Delaware, and Nevada. It's not chance in fantasy sports that we should be cautious about—it's keeping the hapless sheep away from the well-prepped wolves. ☺

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an interesting discussion about San Francisco Giants catcher and former National League MVP Buster Posey. I'd rostered him several times while I played and seriously considered him for most of my games. But Jennings dismissed him almost outright. If there's one position he skimps on, it's catcher. It's the position that offers the least return on investment; so fielding a low-priced catcher usually won't cost you a ton of points relative to your peers. Further, Posey, Jennings said, plays in "a pitcher's park," meaning it's harder to hit home runs because of the swirling winds near the San Francisco Bay. In fact, Jennings is only likely to have Posey on one of his teams if the Giants happen to be playing in Denver's Coors Field, the ultimate hitter's park thanks to the high-altitude city's thin air.

With my nominal research I put together a record of 14-16, a roughly 47 percent win fraction. But that kind of winning percentage means that daily fantasy sports is not a money-making proposition for me.

—Nikhil Swaminathan



The Real Bliss of the Sports Fan

Why we get off on the game—and are better off for it

BY BRIAN BARTH

SPORTS FANS AREN'T TYPICALLY in the mood for academic research in the minutes before a big game. But Paul Bernhardt, an aspiring young behavioral scientist at Georgia State University, was determined. Armed with a bag of sterile vials, Bernhardt inched through the crowd at Atlanta's Omni arena, politely asking anyone decked out in either University of Georgia or Georgia Tech basketball garb—the teams that were set to battle that evening—for a bit of saliva.

The year was 1991. Fans of the Bulldogs and the Yellow Jackets, the state's two most renowned collegiate sports institutions, had been hating each other's guts since 1893, a rivalry affectionately known as COFH: Clean, Old-Fashioned Hate. (Yes, sports rivalries can have names; COFH is historically significant enough to have a 5,000-plus word entry in Wikipedia with 50 citations.) Bernhardt wasn't there to celebrate a century of feuding, however; he was hoping to break new ground on the scientific understanding of such fandemonium—"highly identified" fans would be the proper psychology term—to explain why being a sports nut, bitter hatred and all, feels soooo goooooood.

The fact that athletes experience a tidal rush of testosterone, a hormone associated not just with male sexuality but with self-esteem, upon winning a big game was well established. But there was a hypothesis floating around among social psychologists at the time that fans ride a similar hormonal high. Bernhardt just needed a little spit, which offers a reliable approximation of the body's biochemistry at any given moment, to find out.

"I'm sure people thought I was wacko, but it's easier to get people to give you little spit than a little blood," says Bernhardt, now a professor of psychology at Frostburg State University. "The woman I was dating at the time, who was with me, was so traumatized she buried her head in the book she'd brought."

The game was extremely close, with UGA squeaking out a win at the buzzer. In the post-game chaos only eight fans, four Dawgs and four Jackets, returned their bottles—but the results were compelling. Testosterone levels typically peak shortly after waking each



day, then drop about 35 percent by bedtime. When he got back to the lab Bernhardt discovered that the testosterone levels of the four jubilant winners were 20 percent higher as they exited into the late-night melee outside the Omni than when they entered. Players are known to experience roughly the same increase. (The Georgia Tech fans, meanwhile, had a 20 percent drop, though Bernhardt places less importance on that finding, as testosterone levels typically decline at that hour anyway.)

Soon after, he and his colleagues carried out another test with a larger, more statistically significant pool of subjects: 26 soccer fans watching a Brazil-Italy World Cup game in Atlanta, half at a Brazilian sports bar and half at an Italian bar. Again, a 20 percent increase in testosterone was observed among fans of the winning team, the Brazilians (along with a corresponding 20 percent drop for the Italians). "Statistically, the correlation is very strong," says Bernhardt. "The importance of [the experiment] was to show that testosterone isn't just about a body getting pumped up; it's not, for want of a better term, about being burly. It is about a sense of status, of seizing the moment." Testosterone is produced during moments of intense competition, even if the experience is purely psychological. "The fans are having a vicarious experience of the competition, as well as the experience of status gain that comes with that," he says. Similar studies since then have confirmed this relationship, while others suggest that the entire panoply of neurochemicals associated with

athleticism, from dopamine to adrenaline to oxytocin, are triggered to a similar degree in both the players and fans during a game.

Thus it seems that fans can share much of an athlete's thrill, without all the talent, training, and exertion.

BERNHARDT MAY HAVE OPENED THE DOOR on an important physiological dimension of fan behavior, but a broad conceptual framework explaining the human compulsion to watch other people play games—a condition that affects approximately 60 percent of Americans—was already coming into focus.¹ In 1976, psychologist Robert Cialdini led a series of studies in which students of seven major football schools were gathered into lecture halls on a Monday following a big game. At schools where the team won, the percentage of students wearing team colors and apparel was far greater than at the losing schools. While the average sports fan might say, *duh, of course they were*, Cialdini's experiment was intended to provide empirical evidence in support of a concept he called Basking In Reflected Glory: “publicly announcing one's association with successful others even though [one] ... has done nothing to bring about the other's success.”

BIRGing, as it is now known in psychology-speak, is a subconscious strategy to maintain a positive self-image. “I was absolutely BIRGing with joy after the Dawgs kicked their Yellow Jacket asses,” one's subconscious mind might say, if only it could speak.

But what of the losers? It turns out they have clever strategies for feeling good, too. The first stage of coping with a loss is often CORFing—Cutting Off Reflected Failure. Here Cialdini's research revealed that pronoun choice was highly subjective. BIRGers will say, “We crushed them,” while CORFers invariably distance themselves from the failure: “*They* blew it.” Losers may then continue with a suite of mnemonically-termed coping mechanisms, including: BIRFing—Basking In Reflected Failure, the underdog mentality; CORSing—Cutting Off Reflected Success, as in the nostalgic fan who rejects success gained through deceit (i.e. doping) and opines for the more pure glory of times past; and COFFing—Cutting Off Future Failure, a strategy of not getting too excited when a team with a historically poor record starts to do well (lest their success prove to be short-lived).

Highly identified sports fans have an above average sense of meaning in life.



These ups and downs of fandom help keep us plugged into the game, part of the perverse bliss of sports that psychologists refer to as “eustress,” a type of beneficial stress that is flavored with a touch of ecstasy. So while BIRGing and CORFing may seem like the silly, predictable machinations of the average sports fan, they underscore a shared sense of identity.

Daniel Wann, a social psychologist at Murray State University, has spent the last 30 years elaborating on Cialdini's theory that identification with sports teams is, at the very least, a means to boost self-esteem—if not an opportunity to enhance overall mental health, he adds. Wann and his colleagues have carried out more than 20 studies in which diverse groups of sports fans, including high school students, college students, senior citizens, Australians, female fans, hockey fans, NASCAR fans, and others, were evaluated in regards to various measures by which psychologists gauge well-being—such as a sense of self-worth, frequency of positive emotions, feeling connected with others, belief in the trustworthiness of others, sense of vigor and energy, and so on. In virtually every single study, the degree of fan identification—that is, how devoted and enthusiastic a fan is—shows a positive statistical correlation with one or more of these factors. Wann's Team Identification-Social Psychological Health Model, first published in 2006, describes nearly two dozen



CLEAN OLD-FASHIONED HATE Georgia Tech Yellow Jackets bond over their shared hatred of the University of Georgia Bulldogs.

“well-being benefits” that he says are commonly associated with sports fans.

Using mediation analysis, a statistician’s approach to differentiating causality and correlation, he’s found that sometimes the well-being benefits flow directly from fandom—a sense of belonging, for example—while other times there is a “mediating” factor—I’m more trusting of others *because* I have a strong sense of belonging in regards to my team. In all cases there was a causal connection between fandom and well-being, but sometimes the link was indirect. Similar phenomenon can be observed in other instances of strong identification with a group, whether a gang or a church congregation, though few cultural institutions today have as many die-hard adherents.

And the rules don’t apply as well to casual fans, Wann cautions. “This effect is most prominent among those who are most intense. In order to really reap the well-being benefits of fan identification, it needs to be a central part of your overall social identity.” The biochemical aspects of fandom only serve to reinforce those good feelings.

His most recent study, which is pending publication, found that highly identified sports fans have an above average sense of meaning in life. This was one of those cases where A leads to B, but as a result of C, the mediating factor: “We found that identification wasn’t necessarily leading directly to meaning, but rather it was going through belonging,” says Wann. “So identification leads to belonging, which in turn leads to a sense of meaning.”

Wann believes there is one very simple reason fans are so deeply fulfilled, which has nothing to do with sports itself. It’s not about winning or losing, he suggests; it’s about the human bonds we form in the process. “If you identify with the local team, that’s going to give you connections to others around you, and those connections will give you a sense that there is meaning in life. For example, if you are a Kansas Jayhawks fan”—which Wann, a University of Kansas alumnus, is—“and you happen to live in Lawrence, Kansas, and you’re out in the streets with your Jayhawks shirt on and your hat and your bumper sticker and all that, it’s really kind of hard to feel lonely. You have so many friends, so



to speak, that you'll feel connected to. You might not even know their names, but you feel as though you are unified with so many other people in the community."

AFFILIATION WITH SPORTS TEAMS, it seems, is a contemporary form of tribalism. "Our sports heroes are our warriors," Cialdini once remarked. And tribal affiliation, along with satisfying our need for a sense of belonging, produces another social pleasure that's not so warm and fuzzy: the good vibes of walloping your opponent. It's what Germans call *schadenfreude*, literally "harm-joy," the pleasure derived from others' misfortune.

Mina Cikara, director of the Harvard Intergroup Neuroscience Lab, says that while ingroup-outgroup dynamics stemming from this infallible aspect of human nature may lie at the roots of racism, religious intolerance, and war, she sees sports as a potentially constructive outlet for the tribalist tendencies of modern humans—we get much of the pleasure with little of the harm. Using fMRI imaging, Cikara observed the brain activity of 18 diehard Red Sox and Yankees fans (who have been mortal enemies ever since the Red Sox dealt Babe Ruth to the Yankees in 1920) while subjecting them to video clips from ESPN's Gamecast. Upon witnessing their favored team score or strike out an opposing player, a flurry of activity is seen in the ventral striatum, a region of the brain associated with reward-based decision-making, as well as addiction.

"The dopamine is saying, 'hey, hey, that was good, let's make sure to do that again,'" says Cikara. The effect was observed not just with clips where the Red Sox and Yankees played against each other, but

also in another set of clips where each team faced off against the Orioles. When Yankees fans saw the Red Sox perform poorly against the Orioles, which had no direct bearing on their team's success, they were rewarded with a hit of dopamine just the same: pure *schadenfreude*.

Cikara studies *schadenfreude* in the political realm as well, but says that sports fans make good guinea pigs because they're willing to self-report feeling pleasure in response to the misfortune of others. Her work is aimed at finding strategies to head off the worst outcomes of the 'us versus them' mentality. With the intensely polarizing social dynamics found in so many other cultural contexts, where putting down the 'other' often leads to grave consequences, sports may be an important relief valve.

"There is a script of being a good fan which means talking shit to the other fans," says Cikara. "That allows for the enactment of some of these tribal behaviors in a space where it is acceptable and anticipated. Sports is a place where we as a society have decided that it's OK to say nasty things and root for the downfall of another." And that is perhaps more gratifying than we realize. ☺

BRIAN J. BARTH is a Toronto-based writer focused on culture, science, and the environment.



REFERENCES

1. Jones, J.M. As industry grows, percentage of U.S. sports fans steady. Gallup.com (2015).



ILLUSTRATION BY **DANIEL SAVAGE**

Hierarchy problem

Matter-antimatter asymmetry

Dark matter



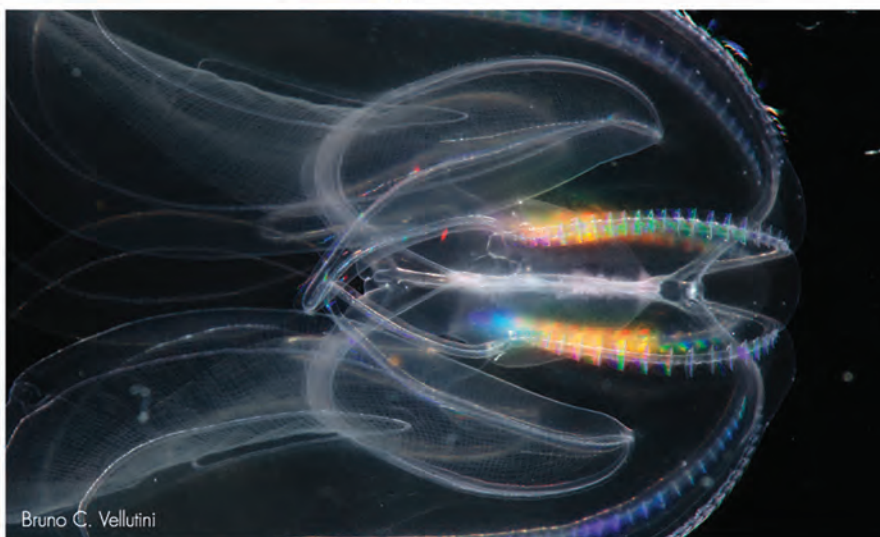
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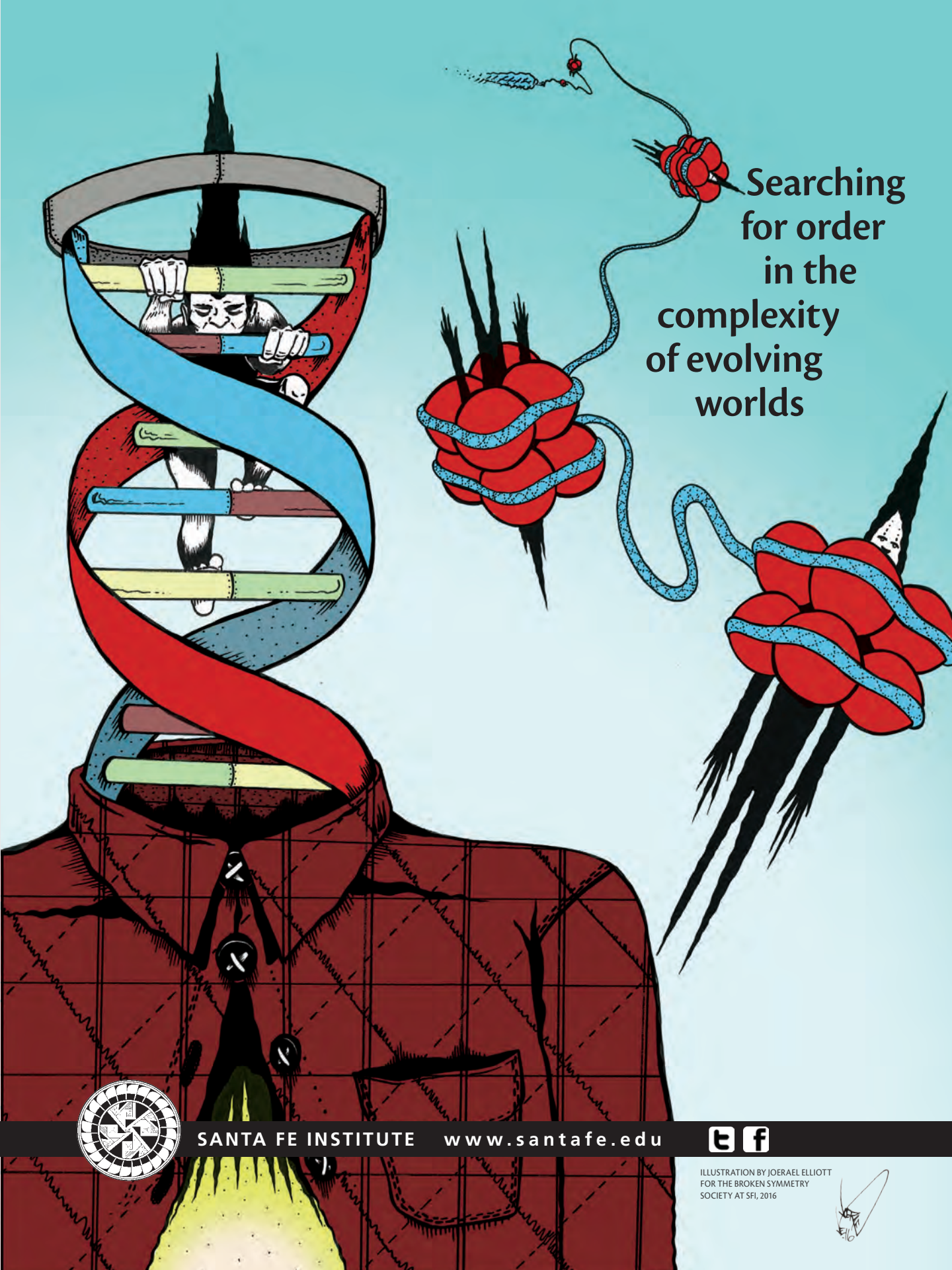
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FOR THE BROKEN SYMMETRY
SOCIETY AT SFI, 2016



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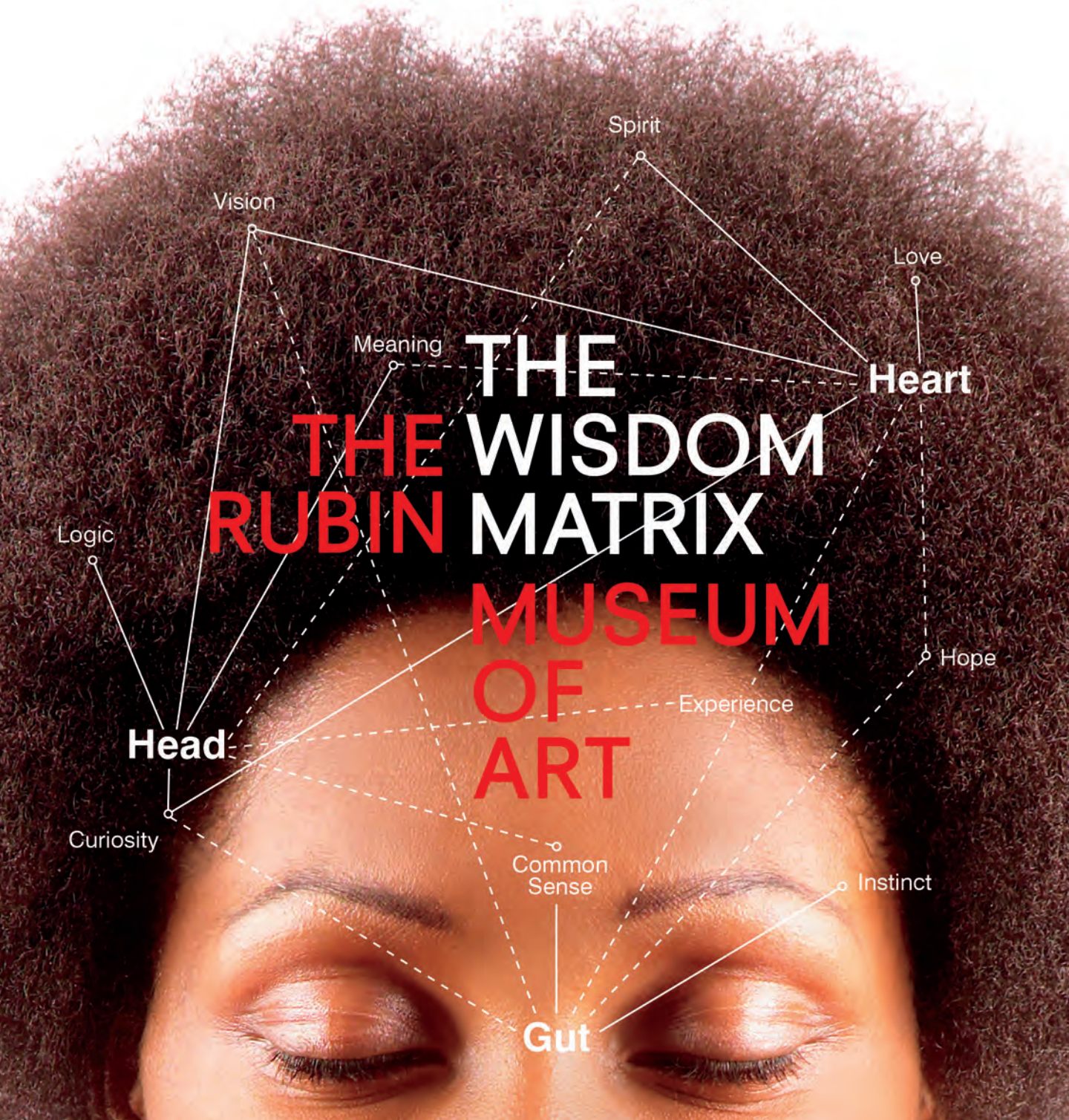
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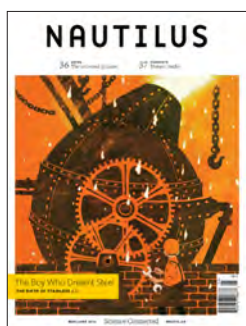
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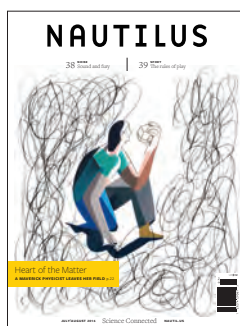
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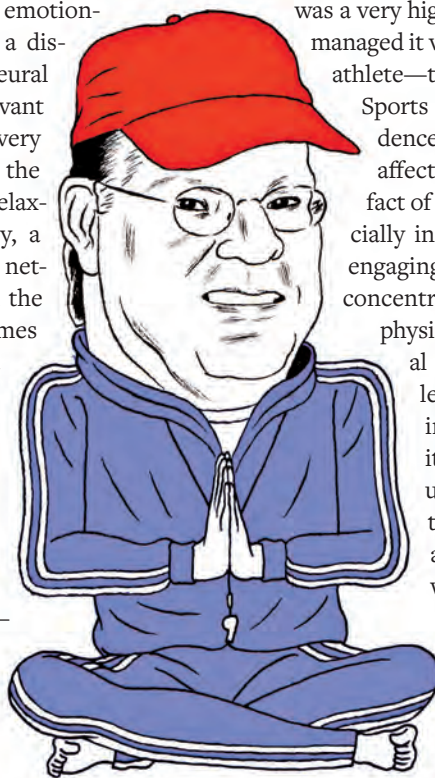
Brad Hatfield

*The kinesiologist and cognitive neuroscientist
reflects on the themes in Nautilus*

INTERVIEW BY ZACH ST. GEORGE

NOISE

My colleague and I recently studied the brains of professional football players using a magnetic resonance imaging machine. Compared to healthy-but-untrained young men, the brains of the football players tended to have much narrower responses to emotional situations. Basically, you have a disengagement of any nonessential neural processes and a locking-on of relevant neural processes, which creates a very specific engaged mental state. In the brain, you would see an overall relaxation of cerebral cortical activity, a sort of quieting. The attentional networks are probably very active in the expert, but everything else becomes reduced and inhibited. It's not a quiet, sleepy brain, but a brain that is precisely and remarkably matched in its engagement with its task demands. The brain gets busy when it's under stress. People think too much, and then they aren't consistent. I think that's a lesson that goes beyond sports—for a surgeon, for someone giving a speech. Keep it simple. Don't think ahead too much. You've got to keep that brain quiet.



SPORT

I got interested in the psychology of sport because I was very nervous as an athlete. I always admired Chris Evert. She seemed like a machine to me—whether she was ahead, behind, whatever. It turns out that she was a very high-stress performer, but apparently managed it very well. That's what makes a great athlete—the ability to reduce mental noise.

Sports are mental. There's very good evidence that physical activity in children affects development of the brain. The fact of the matter is that movement, especially in sports, is tremendously mentally engaging—you're using your powers of concentration, visual-spatial coordination, physical coordination, timing, emotional regulation. Look at high-level athletes; they are a tremendous study in concentration and focus, and it's a rare person who can perform under such a high level of expectation. There's something very special about what they've trained. I think we've trivialized sport a lot, put too much emphasis on winning and losing. As powerful as sports are, culturally and as an economic engine, we tend to not think of them as very serious. ☺

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