# NAUTILUS



## A Philosopher Among Flies

**TRUTH AND BUGS ON A SWEDISH ISLAND** p.20

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**MARCH/APRIL 2015** Science Connected **NAUTIL.US**

# Arcades and Hoverflies

**PONG IS NEVER GOING** to be the same. Released in 1972, it became one of the first widely popular video games, and is today an icon of the dawn of the gaming era. Vintage pong consoles are bought and sold for hundreds of dollars. There are pong-based jokes (few are funny) and pong retrospectives.

But on February 25 of this year, its status evolved. It became one of a handful of games that is reliably played better by a computer than a human, even when that computer starts with no instructions or information of any kind. Just like that, one of the first video games made by man became one of the first to be mastered from scratch by artificial intelligence.

The remarkable result, achieved by Google DeepMind, could not have happened without our ever-increasing mastery over data. DeepMind's software started by processing an avalanche of raw pixel brightness levels before independently creating the rules and strategies it needed to succeed, a triumph of the information age.

So information can enable. But stripping it away can also enable, as Fredrik Sjöberg suggests on page 20 of this issue. Having spent seven years collecting hoverflies on a tiny Swedish island, Sjöberg discovered that, while "television has taught us to see nature ... as something immediately comprehensible, that is only an illusion." To escape the illusion, Sjöberg learned to read the landscape of his island like a language, finding a bit of himself in the process.

Information, illusion, creativity—welcome to the March/April print edition of *Nautilus*.

—Michael Segal
Editor in Chief

**PS:** We are proud to announce that *Nautilus* will now be published in print six times a year, instead of four, with slimmer, friendlier issues. Expect us to visit a bit more often.

**NUMBER 07** | MARCH/APRIL 2015

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OLIMPIA ZAGNOLI

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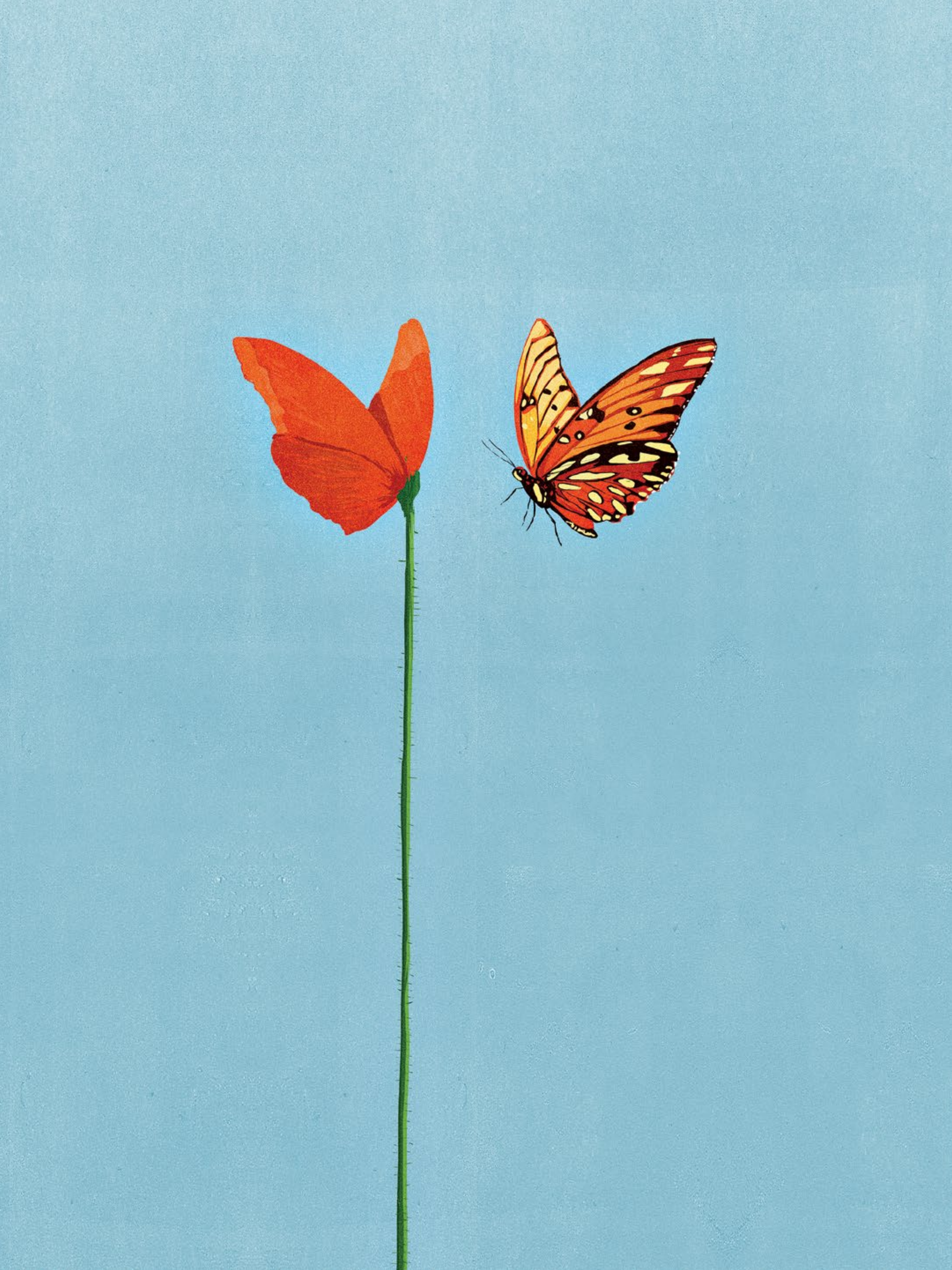
## Illusions

"Our brain may have registered the unreliability of the image subconsciously, and decided not to spread the news."

—Tom Vanderbilt, p.36



**THEME ART** Shout



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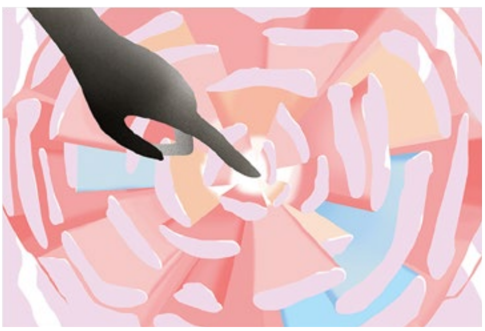

## Creativity

"Two personality traits tend to show up again and again among innovative thinkers. Unsurprisingly, openness to new ideas is one. The other? Disagreeableness."

—Kirsten Weir, p.68



**THEME ART** Jon Han

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## Information

"Late at night, McCulloch and Pitts alone would pour the whiskey, hunker down, and attempt to build a computational brain from the neuron up."

—Amanda Gefter, p.94



**THEME ART** Bratislav Milenkovic


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# Preludes

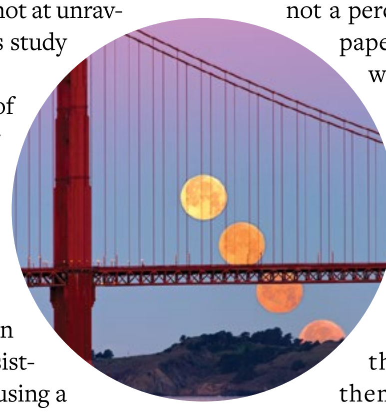
PSYCHOLOGY

## Your Brain Can't Handle the Moon

*How the moon stirs tension between your conscious and subconscious mind*

**WHY DOES THE MOON** look bigger when it's near the horizon? It sounds like a simple question, but since astronomers began puzzling over it 3,000 years ago, the "moon illusion" remains a quandary even to neuroscientists who study perception today.

No scientist has wrapped his brain around the illusion more tightly than Lloyd Kaufman, a cognitive psychologist, retired from New York University. After Descartes, Galileo, and Newton had their shot at unraveling the illusion, Kaufman, in the 1950s, settled into his study to set the misbegotten moon gazers straight.



FLICKR / DAVID YU

Up to that point the best hypothesis was "angle of regard." It was based on the angle that our eyes (or head) make relative to the horizon. The more your eyes are angled upward, the smaller something looks, due to the physiology of our visual system. Sounds good, said Kaufman. It's wrong.

In a 1962 paper, Kaufman and his colleague pointed out that if you looked at the horizon moon with your chin tucked in and your eyes elevated, the moon illusion persisted regardless. The duo performed a set of experiments using a device that could place a disk of light in the sky so that it was "exactly like looking through a window at the moon." They concluded that if an observer's view of the terrain is obstructed, the illusion vanishes.

This observation supported an earlier hypothesis known as "apparent distance." The presence of terrain increased the subjective sense of distance to the moon, so that while it was actually the same size, the perceptual system would "conclude" that it was a more distant object and inflate its size.

Kaufman even called the astronaut Ed Lu when he was in the International Space Station to ask him if he saw the moon illusion up in space. Lu said no. "There's nothing there but the curvature of the Earth," Kaufman told me. "You got no distance."

But that doesn't mean the question was settled—there was still the size-distance paradox. The traditional description of the paradox involves three consecutive acts of perception: We perceive the moon to be farther away because of terrain; we perceive it to be larger because it is farther away; we perceive it to be closer because it is larger. Kaufman thinks that last step is a judgment, not a perception. In a 2007 paper, Kaufman said we need to remember that "perceptions are outcomes of computational processes far more numerous and complicated than the perceptions themselves." Spelling out the exact error is hard because "it's not intuitive," Kaufman said. "When I try to make it explicit, I run into a lot of difficulty, and that's why I'm hung up on this last paper I'm doing." Precisely explaining the mechanics of our vision is a problem Kaufman shares with some august company. It was Kepler who wrote four centuries earlier that "perception does not belong to optics but to the study of the wonderful."

*—Brian Gallagher*

ILLUSTRATION BY JOANNA NEBORSKY

FICTION

# The Hit Book That Came From Mars

The Martian *started as a self-published blog, and became a major motion picture*

**THE STORY OF ANDY WEIR** is a strange mix of fact and fiction. There's the fairy tale success of his book, *The Martian*, which rose from a series of free blog posts to the *The New York Times*' fiction best-seller list. Then there's the story inside the book itself: An astronaut gets left behind on Mars in a near-future NASA mission, and has to survive until help comes. This he does through physics and chemistry, algebra and pipe fitting, botany and celestial navigation, all described in meticulous detail. I spoke to Weir this December.

***You've said that science can create plot. How did it do that in* The Martian?**

I had my astronaut who's stranded on Mars. All you have to do is start examining any aspect of his survival and you'll quickly find the problems he runs into. He's going to need food, but you can't just create food that easily. Doing some math on how long his supplies would last told me, well, it's just implausible for his supplies to last long enough. So that's a simple case where science creates plot. Doing the math on every little aspect of his life revealed the many places where he was in mortal danger.

***Your book seems to appeal unapologetically to a nerd audience.***

Yes, I think that's definitely accurate. When I wrote it, it was a serial that I was posting to my website one chapter at a time. I had about 3,000 regular readers that I'd accumulated over 10 years of writing fiction and web comics and stuff like that. I was really writing it for them. I didn't have market appeal in mind when I was writing the book. I don't know how this story that was basically a prolonged math problem ended up getting so popular among people who aren't that interested in math!

Doing the math revealed the many places where he was in mortal danger.

***How important was getting the science right?***

One of the things I get from readers is that they had complete confidence in the legitimacy of the science. You don't need to actually be right, you just need to sound right. You just need the reader to have faith in you. When I'm reading a book there's a meta process going on in my brain, just critically analyzing things. It's like, oh, I don't know if that's realistic! If you can make that voice in the reader's head not have much to say, then they enjoy the book more.

*—Michael Segal*

ILLUSTRATION BY MATT TAYLOR

GENETICS

# Your DNA Is Nothing Special

*It's time to relax about genetic testing*

**WHO'S YOUR DADDY?** It's a fair question. A meta-study published in 2006 by a University of Oklahoma anthropology professor estimated that 30 percent of men who have low paternity confidence about a child were justified in their suspicions. Even among men with high paternity confidence, about 2 percent were cuckolds. Predictably, that 2 percent margin of error has led to some uncomfortable situations.

A hyperventilating, cautionary report posted at Vox.com trumpeted that genetic testing can unexpectedly tear families apart with revelations that are especially painful. As the databases at testing sites such as 23andMe grow, it warned, "there will be more and more family reunions, many of them by users who have no idea they are coming and aren't prepared for them."

The Vox report irritated Blaine Bettinger, who blogs as The Genetic Genealogist. He argued it unfairly castigated DNA as a home wrecker. After all, Bettinger pointed out, census records, birth certificates, wills, and many other records have the same potential. Further, most people are overjoyed to discover lost siblings, or birth parents, or re-connect with children given up for adoption. Startling tales of discovery are also extremely rare: While Vox reported that some 7,000 users at 23andMe discovered secrets about parents or siblings, a 23andMe spokesman said that calculation was based on a guess that about 1 percent of its users had discovered a relative they didn't know about, and that discovering distant cousins was far more common than anything about parents or siblings. The lost relative must also be a member of the site, which makes a match all the more unlikely.

Bettinger labeled Vox's sky-is-falling approach as an example of "genetic exceptionalism." The term was coined to describe the fallacy that our genetic code is so powerful it deserves special protection beyond that given to other kinds of personal information. While geneticists generally don't subscribe to the notion that genetic information is exceptional, the public is another story. According to public opinion surveys, we vastly overestimate the predictive power of genetics. The public frets that employers and insurance companies will use genetic tests to fire them, hike their rates, or deny coverage. They fear insurers and employers will use the power of genetics against them, because those groups believe in the same power—an infinite loop of ignorance.

*—Chip Rowe*

OLIMPIA ZAGNOLI

COSMIC

# One Question for Christof Koch

*Why do you say "some deep and elemental organizing principle created the universe"?*

**WE LIVE IN A UNIVERSE** where a complex piece of organized matter gives rise to conscious experience. Isn't that amazing? Is it a chance event? Is there an infinite number of universes and we just happen to find ourselves in this one? Looking back over 13 billion years of cosmic evolution, then 4.3 billion years of terrestrial evolution, then 4 billion years of biological evolution—here we are, complicated creatures, and evolution is ongoing. For reasons I'm utterly unable to justify, I find this all deeply mysterious and deeply beautiful.

*— Christof Koch is chief scientific officer at the Allen Institute for Brain Science.*

# These Males Are Cheating Animals

*The tricks they play would make Darwin blush*

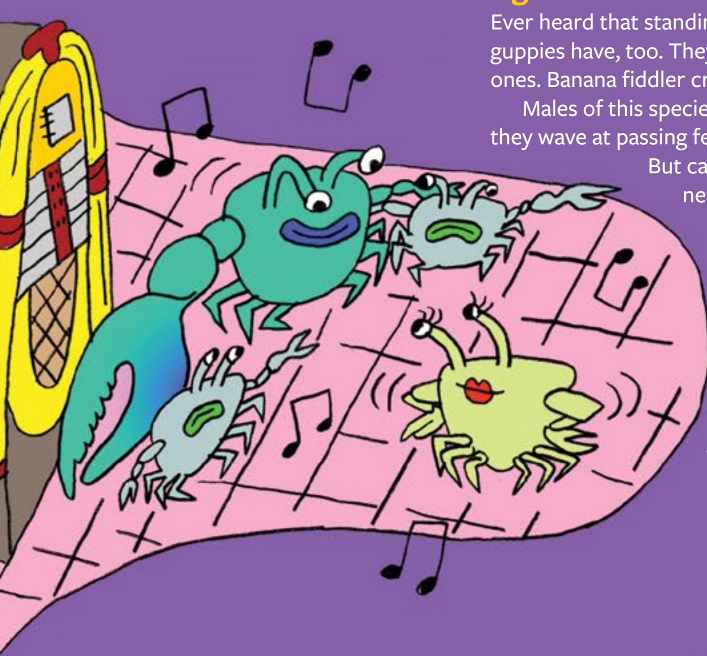
**BY ALEX RILEY**

ILLUSTRATION BY VANESSA DAVIS

**WE THINK OUR OWN** relationships are wrought with lies and intrigues, but this is nothing compared to the lengths animals will go to in their efforts to pass on their genes to the next generation.

"The battle of the sexes is really ingrained in much of animal mating behavior," says Karim Vahed, an entomologist from the University of Derby whose work focuses on sexual conflict. "The evolutionary interests of males and females over many decisions—like how often to mate, when to mate, who fertilizes the eggs—are often in conflict."

As a result, the process of sperm fertilizing egg has led to some incredible examples of exploitation, manipulation, and deception. From the birds to the banana fiddler crabs, here are the great tricksters of sex.



## Ugliness Is Relative

Ever heard that standing next to an ugly friend makes you look better? Male guppies have, too. They prefer to display next to drab males than more colorful ones. Banana fiddler crabs (*Uca mjoebergi*) may be using a similar trick.

Males of this species possess one amusingly enlarged yellow claw that they wave at passing females. Females generally prefer males with larger claws. But can males make their claws seem bigger by standing near smaller males?

Although evidence of males actively associating with such inferior competitors is lacking, females have been shown to prefer males depending on who their neighbors are. When presented with a choice between five robotic claws—two large, two small, and one medium, focal claw—that act as simulacrums of the waving display of males, females have been shown to prefer the central claw when it was immediately next to smaller claws compared to larger ones.

## Empty Gifts

The human tradition of wooing women with chocolates can't hold a candle to what decorated crickets (*Gryllodes sigillatus*) do. During sex, a female decorated cricket mounts the male. Then, after he has carefully placed his spermatophylax—a central capsule of sperm coated in a thick, detachable gelatinous layer—onto the female's genital opening, she excitedly tears the outer layer away with her trembling mandibles and begins to feed. At the same time, the sperm capsule clings to the female's reproductive tract and starts transferring the male's ejaculate. The taste and texture are irresistible to the female. But it imbues no benefit to her health or the number of offspring she can produce. "They're a sham," says Scott Sakaluk, a behavioral ecologist from Illinois State University. "Its primary goal is to keep the female happy and occupied during the time it takes for this insemination process to occur."

## Size Matters

By constructing a bower—a structure composed of two parallel walls of sticks leading onto two courts containing a variety of objects—male great bowerbirds (*Ptilonorhynchus nuchalis*) aim to woo a female with their building prowess and artistic aptitude. The collections of stones, bones, and bleached snail shells that cover the floor of their courts increase in size the farther they are from the thatched walls. When the female stands inside the alcove created by the two walls and looks out onto the court, this positive size-distance gradient creates the illusion that the ornaments are of the same size. The male then parades a variety of colored objects in front of this monochrome, foreshortened background. This background may make the male's bright decorations appear larger and more vibrant, increasing his attractiveness to the inquisitive female. On the other hand, this could just make the male's display easier to see, because the background is uniform.

## Small and Stealthy Does It


Marine isopods (*Paracerceis sculpta*) keep their "harems" of up to 20 females inside the porous cavities of sea sponges. An alpha male guards the entrance of these so-called spongocoels against competitors.

Some males mimic females to gain access into the spongocoels. But others, called gamma males, use a much simpler approach: stealth. Smaller, speedier, and very much like a juvenile isopod in appearance, these males are able to dart into the cavity and hide. Once there, they wait for one of the virgin females to become sexually receptive.

Gamma males have one other advantage over female mimics and alpha males: their investment in ejaculate. "Almost all of their body cavity is devoted to sperm," says zoologist Stephen Shuster at Northern Arizona University. So even if they only get a few trysts, gammas still do just as well as alphas.

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ALEX RILEY is a science writer based in London. He also studies the teeth of sharks and rays at the Natural History Museum.

# The Philosopher King of the Hoverflies

*A roving meditation on nature, literature, and the joy of collecting flies*

**BY FREDRIK SJÖBERG**

A**S I NOW LIVE** on an island in the sea and am not an expert on anything but hoverflies, we will simply have to start there.

In short, my artistic sense remained relatively undeveloped, and my past, as always, caught up with me. When anyone asked, therefore, I said succinctly that hoverflies are meek and mild creatures, easy to collect, and that they appear in many guises. Sometimes they don't even look like flies. Some of them look like hornets, others like honeybees, parasitic ichneumon wasps, gadflies, or fragile, thin-as-thread mosquitoes so tiny that normal people never even notice them. Several species resemble large, bristly bumblebees, complete with in-flight drone and coats flecked with pollen. Only the expert is not deceived. We are not many, but we grow very old.

Nevertheless, the differences are great, in fact greater than the similarities. For example, wasps and bumblebees, like all the other hymenoptera, have four wings, whereas flies have only two. That's elementary. But it's a thing people seldom see, principally because flies can easily achieve several hundred wing beats per second.

The entomological literature that began to fill my island house tells of a Finnish scientist named Olavi Sotavalta, whose interests included an investigation of insect wing frequencies. In particular, he occupied himself with the biting midges, which manage to reach an astonishing frequency of 1,046 wing beats per second. Sophisticated instruments in his laboratory allowed him to measure exactly and unambiguously, but just as important for Sotavalta's research was his wonderful musicality and the fact that he had perfect pitch. He could determine the frequency simply by listening to the hum, and the foundation of his renown was laid when, in a famous experiment, he managed to trim the wings of a midge in order to increase the frequency beyond the limits of what seemed possible. He warmed up the midge's tiny body several degrees above normal and cut its wings with a scalpel to minimize air

ILLUSTRATIONS BY YUKO SHIMIZU

resistance, whereupon the little beast achieved no less than 2,218 wing beats per second. It was during the war.

In my mind's eye, I see Olavi Sotavalta lying on his back in his gray-green sleeping bag somewhere in the bright summer nights of northernmost Finland, maybe on the shore of Lake Inari, smiling to himself as he listens to billions of hums from the space around him, thin as filaments of mica.

But I was going to talk about disguises, about the art of mimicking a bumblebee. We all know why. Profitability. Birds like to eat flies but usually avoid hymenoptera, which can sting. And so nature's perpetual arms race has formed masses of harmless flies into lifelike reproductions of all sorts of unpleasant things. I don't know why hoverflies have become such superb impostors, but that's what's happened, just as surely as the sun was shining from a clear blue high-summer sky one day when, at the very beginning of my career as a fly expert, I stood on watch in a clump of bishop's weed in bloom. There were insects everywhere. Pearl butterflies, rose-chafers, longhorn beetles, bumblebees, flies, all sorts. And me, of course, wearing shorts and a sunhat, armed with the blissful thoughtlessness of the trigger-happy hunter and a short-shafted, collapsible tulle net of Czech design.

Then, suddenly, a coal black missile came in from the right two metres above the nettles. I had just enough time to think 'stone bumblebee,' no more, but within a fraction of a second I also thought I sensed a strange lightness of behavior. Very subtle, barely perceptible, but the very suspicion released a reflex backhand sweep of my net.

That catch came to be my ticket of admission into hoverfly high society.

But first, a more comprehensive setting of the scene. We'll need to take this from the top. And what better place to start than with a description of how the hunt takes place. We are all familiar with the conventional image of the entomologist as a breathless twit rushing wildly across fields and meadows in pursuit of swiftly fleeing butterflies. Quite aside from the fact that this image is not entirely true to life, I can assure you that it is utterly incorrect when it comes to collectors of hoverflies. We are quiet, contemplative people, and our behavior in the field is relatively aristocratic. Running is not necessarily beneath our dignity, but it is in any case pointless because the flies move much too fast. Consequently, we stand still, as if on guard, and moreover almost exclusively in places with blazing sunshine, little breeze and fragrant flowers. Passersby can therefore easily get the impression that the fly hunter is a convalescent of some kind, momentarily lost in meditation. This is not wholly inaccurate.

The equipment is not remarkable. Net in one hand, pooter in the other. The latter is a sucking device consisting of a short, transparent fibreglass cylinder with corks at both ends. A plastic tube runs through one of the corks and a long hose through the other. The tube is pointed carefully at sitting flies, the hose is held in the user's mouth. And if he can get close enough without scaring the fly, a quick intake of breath is all it takes to suck it into the fibreglass cylinder. A fine-meshed filter in the rear cork prevents the animal from continuing on down his throat. Answering constant impertinent questions about his sanity is however unpreventable. Believe me, I have heard every conceivable insinuation and witticism along these lines. So I know from experience that the only way to cool off the grinning idiots is with an unexpected demonstration of the third piece of equipment—the poison bottle.

With the casual ease of a man of the world, I haul it out of my pocket and remark, truthfully, that I have in my hand enough cyanide to put the entire population of the island to sleep for good. All the cheap grins are then promptly transformed into respectful questions about how in hell a person gets his hands on cyanide, which I never reveal. Many experts use ethyl acetate, others chloroform, but I prefer cyanide. It's more effective.

Almost 300 people live on the island.

The big black fly flapped about and died quickly in the poison fumes, and since this occurred during my first summer of fly catching (we had then lived on the island for 10 years), I didn't know right away what species I had captured. I could see it was a hoverfly, that's something you learn in a few days, but it was only later that day, at the microscope, surrounded by teetering stacks of books with titles like *British Hoverflies*, *Danmarks Svirrefluer* and *Biologie der Schwebfliegen Deutschlands*, that I realized it was a rare *Criorhina ranunculi.*

The very next morning, for the first time, the island received a visit from the country's foremost expert on the *Syrphidae*, the hoverfly family. He examined my trophy sceptically but then brightened up, questioned me at length about the place of capture, congratulated me, and then, over coffee, related the following history.

**OF ALL THE HOVERFLIES** in the country, *Criorhina ranunculi* is not only one of the largest and most beautiful, it is also so rare that in the early 1990s the decision was made to list it as extinct in Sweden. At that time, it had not been seen for 60 years. The total number of sightings was three: two in Östergötland and one in Småland.

My newfound friend paused for effect and poured a dollop of milk into his coffee cup. The swifts cried, a great loon was fishing out beyond the dock, and far away I could hear taxi boats in the strait that divides the island from the mainland. It was a hot July day.

The species was seen for the first time in 1874, in Gusum in the province of Östergötland. The man holding the net was no less a personage than Peter Wahlberg, the man who succeeded Berzelius in the post of Permanent Secretary of the Royal Academy of Science in the eventful year 1848. After a long life in the service of research as a botanist and professor of *materia medica* at the Karolinska Institute, he had now worked his way up to flies, which strikes me as reasonable and logical considering the fact that back in 1833 he was one of the founders of the Society for the Spread of Useful Knowledge, later dissolved. He was probably a happy man. His portrait in the encyclopaedia suggests as much. His younger brother, on the other hand, looks mostly angry, as if he suffered from toothache or poor finances. His name was Johan Wahlberg and he was more the adventurous type, known to posterity as an African explorer, big game hunter and manic collector of articles of natural history. He died before his time in a fight with an elephant.

The next time *Criorhina ranunculi* turned up was in Korsberga on the Småland plateau. That was in 1928, the collector was Daniel Gaunitz, and four years later another specimen was caught in Borensberg by his brother Sven, later the author of a series of informative articles including "The Old-House Borer in Mariefred" and "Coprophiles of Åtvidaberg." There was a third brother, too, named Carl Bertil. They came from Sorsele. All of them wrote books, mostly about insects.

Anyway, after Borensberg, *Criorhina ranunculi* vanished for a generation, until the man across the table from me on the terrace managed to find a couple of specimens on the western outskirts of Stockholm. My fly was in any case the sixth one ever seen in Sweden. It was my first triumph. Since then, I and others have seen the species many times, either because it has become more common or, more likely, because we have learned more about which flowers it visits, and when, and what kind of rotting deciduous trees its larvae cannot easily survive without. And how to distinguish it from a stone bumblebee.

The real difficulty turned out to be explaining my happiness to the uninitiated.

**FLY AWAY** As much as Fredrik Sjöberg (above) enjoys explaining to tourists that he collects hoverflies, sometimes he responds to the impertinent question "What are you doing?" with "Catching butterflies."

URBAN BRÅDHE

In his short story "The Man Who Loved Islands," D. H. Lawrence writes:

> The years were blending into a soft mist, from which nothing obtruded. Spring came. There was never a primrose on his island, but he found a winter aconite. There were two little sprayed bushes of blackthorn, and some wind-flowers. He began to make a list of the flowers on his islet, and that was absorbing. He noted a wild currant bush, and watched for the elder flowers on a stunted little tree, then for the first yellow rags of the broom, and wild roses. Bladder campion, orchids, stitchwort, celandine, he was prouder of them than if they had been people on his island. When he came across the golden saxifrage, so inconspicuous in a damp corner, he crouched over it in a trance, he knew not for how long, looking at it. Yet it was nothing to look at. As the widow's daughter found, when he showed it her.

**THE AMERICAN PSYCHOANALYST** Werner Muensterberger has pointed out that many collectors collect to escape the dreadful depressions that constantly pursue them. He takes up the question in his study of the Holy Roman Emperor Rudolf II (1552–1612), one of the greatest of the truly obsessive collectors, and I'm happy to grant his point, at least if we're talking about art or books or other objects that change hands in the marketplace and are more or less difficult to find. People who collect everything, as long as it's curious enough, are especially likely to be engaged in a form of fetishism that does indeed allay anxiety.

I know, for I was once on the verge of buying a house in Ydre solely because a dilapidated outhouse on the property was said to have belonged to the once famous poet and bishop Esaias Tegnér (1782–1846).

Natural objects, on the other hand, are not fetishes in the same way. One reason is that they can seldom be purchased for money. In addition, they almost always lack cultural provenance. Any beetle whatsoever that was caught, pinned, and classified by, say, Charles Darwin, would be a wonderful fetish with which to cure a depression, but such things are impossible to come by. It's true that I own a stuffed peacock whose history is known, including a list of everyone who's owned it since it died in the 19th century, and any desperate character who came along might buy it. But the normal thing these days is that nature collectors catch the

> With the casual ease of a man of the world, I haul it out of my pocket and remark, truthfully, that I have in my hand enough cyanide to put the entire population of the island to sleep for good.

creatures themselves. That's different from dealing in art.

I have a distinct feeling that Freudians in general have a much too diffuse picture of the passions that may express themselves in, say, fly hunting. They are way too locked into their squalid little standard explanations of human behavior. Thus the aforementioned Muensterberger comes to the conclusion that your average collector represents an "anal type" who, if I understand the thing correctly, becomes a collector because in his childhood he was not given sufficient time to play with his excrement. It's breathtaking. Not even my good friend the surrealist poet really fits in that package.

I run into him occasionally at Entomological Society meetings. An odd fellow, certainly, but no worse than the others. I like him a lot, partly because his utterly incomprehensible poems make my own books look like wonders of clarity and logic, partly because in addition to his writings he guards a position as one of northern Europe's most distinguished experts on the range and habits of dung beetles. He was out here on the island a couple of years ago, collecting. Freudians would have gone into ecstasies if they could have seen us strolling through meadows, poking at sheep shit or hunkering down beside a fairly fresh pile of horse manure for a professional assessment. No, these are things they just don't understand.

That I take the trouble to bring up Werner Muensterberger is because he is not always wrong. On the contrary, I think he finds his way through the mist with frightening accuracy when he writes in his book on the psychology of collecting that one thing most collectors have in common is a fairly pronounced narcissism. Well, what can I say? If nothing else, he deserves our attention for supporting his thesis with a touching little story about one of his most interesting cases, a man who falls into the unusual category of "one-object collectors."

This man collects only a single article.

One objection is of course that one article cannot very well constitute a collection. But the man is special in the sense that he displays many of the manic collector's tragicomic characteristics. He is constantly in search of a better, finer, single specimen, and when he has found it, he immediately gets rid of the old one. One object, neither more nor less. And what drives him is a compelling, intense desire to be seen and acknowledged for his exquisite taste, his mastery. The object is he, and vice versa—the narcissistic collector in his most crystalline form.

This is perhaps an option for an art collector with a small flat. But collecting a single fly? I don't think so.

But if you did, it would have to be the narcissus fly, *Merodon equestris*. A highly varied species, somewhat like the Adam-and-Eve among orchids, though with more colors than just two. On top of which it's one of those hoverflies that buzzes in such a distinctive way that you can recognize it with your eyes shut, which produces a particularly restful sense of well-being.

Not that I'm in the habit of wandering around outdoors with a blindfold, but it sometimes happens that I need to rest my over-exerted, fly-spying eyes for a spell and just stare at the clouds, or at nothing, lying on my back in the grass and moss on the granite slopes. And to hear the quite singular buzz of a passing narcissus

Any beetle whatsoever that was caught, pinned, and classified by, say, Charles Darwin, would be a wonderful fetish with which to cure a depression.

fly in the course of such a summer nap is a pleasure, for the simple reason that knowledge is pleasing.

I know this stuff. No one knows more about the flies on this island than I do. The mere sound can be like recognizing someone you know in the crowd on a railway platform. A friend who tells a story, as if in passing, about the yearning of people long since dead for beauty, for the fragrance of an evening in late May when the air is still.

As early as the Middle Ages there were people in our country who were happy enough and rich enough to import narcissus bulbs from distant southern lands. *Narcissus poeticus*, the Easter lily, and other bulbous plants in beautiful and ugly colors began then to bloom in garden beds and parks across wide areas of the country, but oddly enough it was only in the 1910s that the narcissus fly arrived. The man who first spotted it, outside Helsingborg, was a still unknown elementary school teacher named Oscar Ringdahl. He told the world about his find with a short notice in *Entomologisk Tidskrift*. The year was 1911. He was 26 years old. The rest is history, at least for entomologists.

The larvae of the narcissus fly live in the bulb itself, underground, and they probably established themselves in Sweden by stealing a ride in bulbs being sent from Holland. No one knows for sure, of course, but my guess is that's how it happened. One clue is that the famous fly expert George Henry Verrall writes in his 1901 book about the hoverflies of the British Isles how, on June 8, 1869, he caught the very first English specimens of this fly in his brother's garden on Denmark Hill in south London, which received annual shipments of Dutch narcissus bulbs.

The narcissus fly is now common both in England and here in Sweden, even though the various species of the genus *Merodon* are native to the warmer climate of the Mediterranean. Or were. Now they're native here too. This fly may have come as an immigrant from the south a long time ago, but now it has the same residency rights as any other fly. This is my basic political position. Not a very risky one, I have to admit, but that's only because fly politics have never really caught on. Why, I don't know. Spanish snails, mink, wild boar, cormorants, what have you—they all attract a steady stream of populist xenophobes and loudmouths of every kind, but no one cares about flies. Not even the paranoids keep me company. But it is political. And in fly questions I am a liberal and do not insist on a closely regulated transition period before they can be incorporated into our fauna. Let them come. We've got plenty of room.

**THE ISLAND'S POPULATION INCREASES** tenfold in the summer—3,000 people in varying states of freedom. At first you don't see them, for at the start of their holidays they stay in their summer houses with their families, often several generations together. This lasts no more than a couple of weeks at most, or until life in these usually small cottages grows unsustainable and begins to become as threatening as something in a play by Lars Norén. That's when the long walks begin in earnest. My image as a fly collector is in many ways a product of this phenomenon—because I answer the questions these restless wanderers ask about what I'm doing and why.

As long as the wild chervil is in bloom, everything is fine, because it grows everywhere and I know some remote spots, ideal for hoverflies, where no other person ever ventures. But when the raspberry thickets bloom and the thistles and the spirea, then I have to stand closer to the roads and the questions.

You get used to it. But sometimes on certain days, the nicest days, when there are a lot of people out and about, I get tired of explaining and start lying instead, like a hitchhiker. They almost always lie, at least on the main roads, for the simple reason that otherwise they'd get sick of their own history. It can be very taxing to stick to the truth for a whole day, in maybe a dozen different cars, answering the same questions about where you're going and why. That's why hitchhikers live such interesting lives. It's all lies. The same is true of fly collectors whom people will not leave in peace.

"What are you doing?"

"Catching butterflies."

That's the cheapest lie. It almost always works extremely well and does not lead to follow-up questions. I believe that the butterfly hunter is seen as a somewhat touching figure, delicate and a little pathetic, a person who ought to be left there in the sunshine without further comment. Just a motherly smile and, tops, an encouraging "I see." No one needs to ask what a butterfly is, and everyone knows there are grown men who collect them.

However it is not entirely risk free, the butterfly lie. If your luck is bad, the person who disturbs your peace may be one of those increasingly common individuals who believe that all butterflies are protected by law and that consequently the collector is a criminal, possibly a pervert. In that case, the dialogue by the side of the road can be both long and tiresome, and in the meantime the flies are flying and so is the time.

"I'm collecting hoverflies" is an equally risky answer. Primarily because it's inadequate. On hearing the word hoverfly, every relatively normal Swede thinks of those small, enervating flies of quite different families, fruit flies mostly, that circulate indoors even in winter among the potted plants. It generally goes something like this:

"Flies!?"

"Yes, hoverflies."

"Boy, you ought to come over to our place. We've got masses of them."

So then you have to clear up that misunderstanding. It takes a while. And once you've said A you have to say B, whereupon you're quickly drawn into a whole seminar about the natural history of hoverflies, their evolution, for example, and their importance for pollination, as well as the uses and joys and technical practicalities of hoverfly collecting, not to mention everything else that has any connection with flies or insects or nature in general. The conversation glides along and suddenly you're standing there with your hands on your hips, philosophizing freely about the prospects for a good mushroom season. It can be pleasant, it really can, and it can bring some days to a close with a productive exchange of views about the modern era's lack of leisure and contemplation. But no flies are caught.

How easily we're transformed into dancers when someone is willing to listen.

"I'm collecting hoverflies" can also be taken as an absurd joke, or, worse yet, as a base provocation. I'll never forget the youngish man who came along on his bicycle one day when I found myself dangerously close to the road. It was when the bishop's weed was blooming in the drainage ditches, so there weren't a lot of really good places to choose among. Roads, gardens, refuse heaps, all of them hazardous places—socially, I mean—but bishop's weed is absolutely unbeatable for collecting flies so I usually grit my teeth and take the risk. The man caught sight of me and braked so hard the gravel flew. A tourist on a rented bike, wearing an open Hawaiian shirt. From the corner of my eye, I saw the way he was looking at me.

"What the hell are you doing?"

His tone was not exactly unfriendly, but I could tell right away that he felt compelled to deliver some observations, as if I were a communal tourist attraction, an EU-financed aborigine placed in the terrain exclusively as a form of outdoor entertainment. Such things apparently exist. Nevertheless, I told it like it was, and since I had just netted a couple of specimens of the magnificent hoverfly *Temnostoma vespiforme*, I handed him my poison jar in order to finish my hoverfly lecture as quickly as possible. He gave my catch a quick glance, handed the bottle back to me, and said:

"Those are wasps."

If nothing else, the trend toward more and more, faster and faster, is preferable to its opposite because you can always get off an express train but there's no good way to speed up a donkey caravan.

"Yes, so you might think," I said, and explained politely about mimicry, whereupon he asked to have another look. I handed back the jar, and this time he studied them long and hard in thoughtful silence.

"Those are wasps."

His tone was now slightly irritated. I stuffed the jar in my pocket. Presumably he thought I was having a little fun with him, or else he simply wasn't used to being contradicted.

The situation was never threatening, more like comic. He lowered the kickstand on his bike, stationed himself with his legs wide apart and his arms crossed over his chest and fixed me with his gaze, as if awaiting my retreat in the face of an intellectually and morally and in every other respect superior opponent. I attempted a neutral smile. No reaction. In fact, he looked a little angry. I decided instead to ignore him, but he stood where he was, immovable. He stood there like that for several minutes, trying to come up with a decisive final word. It was:

"Wasps! And don't you forget it!"

And then he cycled away, his Hawaiian shirt flapping in the breeze.

**I BORROWED THE DANCER** from Milan Kundera. He uses the expression in an elegant comedy about vanity, ambition and the lust for power—just a short dialogue, in simple scenes, that breaks out here and there in a short novel called, precisely, *Slowness*. Well, novel is possibly not the right word to describe it, but it is in any case charming and as double-bottomed as an oil tanker. To be honest, I have never really understood what the book is about, but as with "The Man Who Loved Islands," I was very taken with it before I knew much more than that it existed.

As with Lawrence, I was satisfied for years just to know that a theme that interested me was also of interest to a man of Kundera's calibre. Moreover, I had, as usual, some theories of my own.

Slowness was quite simply a theme granted me by nature.

No, come to think of it, that's not true. It was the summer people who, with their questions, turned slowness into a theme granted me by nature. I had simply told one of them in a moment of inspiration that my fly collecting was a method of exercising slowness. And because that comment was met with an understanding I'm not accustomed to, I continued using that answer and developed my theory later. The reactions were always effusive. As soon as I raised the subject, it was as if everyone in the whole world was, deep down, a fly collector, though they had never realized it before. Some of them had read entire books about slowness and could hold long monologues about the excellence of everything slow.

At the time, I had never discovered that fascination, maybe because I am a rather slow person and had always wished that I was a bit faster. Now, quite unexpectedly, I had become a pioneer in the field. It felt good. I listened eagerly to these summer people fleeing from family life and to their almost feverish lectures about the way our whole age is infected with speed. Communications are faster than ever, the news cycle too. People talk faster, eat faster, change opinions more often, experience more stress, while at the same time the whole world is being transformed at a breakneck pace. The speed of technological development is absolutely sensational, new models of innumerable devices literally pour out on to the market and all of them are faster than the ones that poured out last year, or just six months ago. Computers take the prize, of course, and telephones, but even toasters are now so fast they're approaching the critical limit where the bread gets brown on the surface before it's warm in the middle. And let's not even talk about the markets in currencies and securities.

"Yes, it's terrible," I used to say, and make a few swipes with my net.

This apparently universal, self-generating acceleration does clearly create discomfort and concern of many kinds, and I was always happy to agree.

But to tell the truth, I still think it would be worse the other way around. If everything just got slower and slower we'd all go pretty much nuts and beg for speed with a sincerity that the preachers of slowness never come close to. If nothing else, the trend toward more and more, faster and faster, is preferable to its opposite because you can always get off an express train but there's no good way to speed up a donkey caravan. What's more, everyone has the freedom not to travel and in that way protect themselves from a lot of indigestible impressions and barbaric languages. If you think the torrent—of pictures, messages, people, whatever—goes too fast, then in nine cases out of 10 you can turn it off or just close your eyes and breathe your own air for a while. Most of it is optional. That's the wonderful significance of Swedish prosperity.

But I didn't usually say all that to the summer people.

Some of us can't keep up, it may be as simple as that. It's just too much. We notice it while we're still in school. And since the pipes we learn to dance to are carved by people who love speed and can tame the profusion, we lose our balance and sink into a sullen sense of inadequacy. Some of this can be ascribed to sordid commercialism, but not nearly all of it. Cultural life is a department store, as is science when glimpsed from a distance. Brilliance and speed, helter-skelter.

Slowness is not an end in itself—neither a virtue nor a defeat.

Next summer I think I'll say that my fly collecting is

a way of exercising concentration. A focus so intense that I forget myself. Which is not always so easy on the dance floor of our time. Kundera was on to that. He begins at that end.

**MY OWN GRASP** of temporal spaces so great that they border on eternity is always dependent on that kind of mental prosthesis—clumsy synthetic rulers as a substitute for the deeper understanding I lack. Even the time stretching out beyond the lives of people now living can be hard to get a grip on except as numbers and anecdotes. An inborn feeling for time is presumably the same gift that makes a really good evolutionary biologist or any other kind of historian. I sometimes wish I were one of them, and I have tried, but my downfall is always precisely that sense of time. A couple of hundred years, fine, but then the exhaustion of insufficiency comes creeping in.

That's why I go collecting with my net in the here and now and read my landscape in the present tense. Believe me, even that narrative is rich and full of surprises, however near-sighted you happen to be.

When you get right down to it, my whole history with hoverflies is also a question of comprehension—we might call it language-oriented. Why flies? I realize that I haven't been entirely honest in describing my motives. I've answered the question badly. I was so full of my determination not to lie about some hypothetical benefit that I presented my proclivity for catching flies as a matter of cheap anaesthesia and the simple pleasures of the hunt, an outlet for the vanity of a poor man and the eternal longing to be best. And that may be true, but there is something else too, maybe not greater but anyway prettier. More honorable. It shouldn't be so—an ambitious person's path to the perfection of God-knows-what should be worthy of all honor, if only because a world full of highly personal mastery without petty rivalry would be a nice place to live.

In any case, learning a language is never wrong.

So for a moment let us consider the ability to read the landscape as if it were a language, how to understand nature almost as if it were literature, experience it in the same way that we experience art or music. It's all a question of landscape literacy. Now you may object that all of us, regardless of education and custom, can appreciate beauty in various works of art and pieces of music. That's true. But it's equally true that the untrained sensibility is easily captivated by what is sweetly charming and romantic, which can of course be good but which is nevertheless only a first impression and does not lead very far. Art has a language to be learned; music too has hidden subtleties.

The necessary conditions are more distinct in literature. If you can't read, you can't read. And when I say that the landscape can provide a kind of literary experience at different depths I mean just exactly that—to begin with, you have to know the language. In a vocabulary of nothing but animals and plants, the flies can thus be seen as glosses, telling stories of every kind within the framework of the grammatical laws set down by evolution and ecology.

To recognize a *Chrysotoxum vernale* when you see it, to know why it's flying in just this place and at just this moment, is a source of satisfaction not all that easy to account for. I'm afraid that our path to what is beautiful must first pass through what is meaningful. Which is the more important will remain a matter of taste.

*Chrysotoxum vernale* is very handsome and, in the manner of hoverflies, it looks like a wasp. Anyone who can see the difference can already read, but it gets really exciting only when you can distinguish it from *Chrysotoxum arcuatum*. And by my soul, that's not easy. In years of training, you have to catch both of the twins and examine them on pins, because what is decisive in identifying the species is primarily the color of the inner quarter of the front legs.

Therefore I have collected several specimens over the years. In fact, I have fussed with the *Chrysotoxum* to such an extent that I believe I can tell them apart in the field without even having to catch them in my net. And so I know that *arcuatum* is common, while *vernale* is a rarity. And why is that the case? The question is as open as a half-read novel.

My collection contains six *vernale* from the island, collected in different years between May 27 and June 19. Clearly their fly time is that brief. That's interesting. Even more interesting is the fact that aside from these six flies, this species is known in modern central Sweden from a single specimen—from another island a few minutes of latitude south of mine. The fly is abundant on the islands of Öland and Gotland and in Skåne as well, but it is otherwise absent from the

For a moment let us consider the ability to read the landscape as if it were a language, how to understand nature almost as if it were literature.

mainland. In the 19th century it was collected in Blekinge and Småland, Östergötland and Västergötland, but no longer. Why?

Our knowledge is never adequate, but we know enough to formulate at least a respectably supportable hypothesis. Nothing is more useful than a hypothesis. Particularly because now and then the collector is forced to endure conversations with uncultured individuals who think they know that anyone who would hurt a fly must be immoral and a brute. They're of the ecological persuasion, if I may be pardoned the expression—gentle flagellants who hunker down beside their ill-smelling compost piles and rest easy in the certainty that much of life on earth has run its course. They are severely tormented by nightmares of extermination. You can see it in their eyes.

And so a hypothesis can cheer them up. And *Chrysotoxum vernale* is a good candidate.

With all the rhetorical cunning I can muster, I would like to turn off into a byway and say something partly irrelevant about how Linnaeus was gripped by such wonder and awe in the face of nature's riches when he saw our most beautiful butterfly that he christened it *Parnassius apollo*. Everyone recognizes an Apollo butterfly. In a picture, I mean, because in the real world there are fewer and fewer people granted the gift of watching its fumbling flight across marshy meadows and bare granite. On the mainland, the Apollo has disappeared from most of the provinces where it once flew, and now in these ultimate days it is common only here and along the southeast coast. Something has happened over the last half century. We don't know what, but scientists are investigating and thinking more and more audibly that the land itself is sick where the Apollo used to fly. Increased acidity is thought to leach out elements in the soil that get into the plants and then wind up ... well, they don't really know, but they guess there's a connection.

That the Apollo butterfly still exists here on the island is said to depend on the fact that the bedrock is limestone, which gives the soil the capacity to withstand the poisons and pollution of our industrial society. This is in any case one hypothesis, and it can be transferred word for word to the hoverfly *Chrysotoxum vernale*.

The sceptic feels a bit better at once, partly because he always glows slightly in the cosy darkness of approaching apocalypse, partly because he believes he's speaking to an idealist, a barefoot scientist who has dedicated his life to the heroic task of mapping the evil of the age by searching for flies that will soon be extinct. Suddenly my hunt is pleasing in the eyes of God, almost a praiseworthy testimonial, and that is not a bad description, but to present this empirically cool, scientific usefulness as my primary motive would be simply ridiculous and the height of hypocrisy. That reading is only self-important.

No one learns to tell the song of the woodlark from that of the skylark in order to make it easier to detect approaching catastrophe. All of that comes later. The flies are just smaller and more numerous. The motive is the same, and the reward. Dare I mention beauty?

When the woodlark comes from the south in March, something happens to those who recognize its song.

Something happens to everyone else too, of course, for birdsong is always birdsong, but soon the whole forest is full of robins, hedge warblers, song thrushes, greenfinches, tree creepers, and wrens, all of them singing for all they're worth, and that does dilute that delicate joy. It's only when you can tell them apart and know their names that you can read on and finally understand. The more glosses you know, the richer the experience becomes. Like reading a book. It's rarely the important books that give the greatest reading pleasure.

Television has taught us to see nature like a film, as something immediately comprehensible and available, but that is only an illusion. The narrative voice-over is missing when you go outdoors. What seems great art and sweet music on the surface becomes, for the uninitiated, an impenetrable body of text in a foreign language. So the best answer to the question of why I collect hoverflies is, ultimately, that I want to understand the fine print in the only language that's been mine for as long as I can remember.

In high summer, in July, when all the summer people are lying like seals on the outermost skerries, I often retreat to a remote place on the southern part of the island to read the landscape. On a gentle slope at the edge of a wood, between a hayfield and an avenue of high-voltage towers, there is a large stand of broad-leaved sermountain growing among the oaks and hazels, which, when the sun is at its zenith, attracts fantastic hordes of insects to its large, white umbels. I usually see the noble chafer there, *Gnorimus nobilis*, and out on the hayfield, without a care in the world, are Burnet moths, to whose odd color only Harry Martinson gives full justice: "The prime colour of the wing is a dark, inky, blue-green blue; carmine-red spots shimmer against that background."

On that slope, every summer, I also see the puzzling bee fly *Villa paniscus*, a darting tuft of wool that no one knows anything about and that was thought to be extinct until last year, mostly because few if any people could tell it from *Villa hottentotta* (yes, that's really its name). Bee flies are really for extra credit, but there's something about that slope that attracts me for the sake of reading something other than hoverflies. *Anthrax leucogaster* is also found there, another relatively unknown bee fly, and my latest find was the gold wasp *Chrysis hirsuta*, which is of no interest to anyone, but I wanted to mention it all the same. Partly because there's no risk involved, I mean, no one can suspect me of using my knowledge of some expert's unknown opus to make myself look good, partly because my whole point is that reading nature is a bottomless activity.

I could probably spend a whole life down there (winter doesn't count) without ever getting the feeling that I've now read everything. The hoverflies alone, my personal footnotes, would keep me adequately occupied. For example, the broad-leaved sermountain flowers are often visited by both of the imposing species in the genus *Spilomyia*—not every day, of course, for these are legendary creatures with the power to make environment bureaucrats jump up and down with excitement, that's how rare they are. And the story they tell with their very presence is rich in old, rotting, protection-worthy trees. My heart raced the first time, so great was my eagerness to capture, own, learn and boast with a Spilomyia, and nowadays the feeling is somehow even greater, now when I only see them again—and read. Like the woodlark in March. Might I call it joy?

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From the Book:
THE FLY TRAP by Fredrik Sjöberg

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“THE NECESSITY OF MUSICAL HALLUCINATIONS”
ILLUSTRATION BY **SHOUT**

# 19

**IF ILLUSIONS AND MAGIC TRICKS** seem passé to you, a throwback to when sawing a swimsuit-clad assistant in half still seemed fresh, think again. In 2013, the best ratings the ABC television network earned for any program in its 9:30 to 11 p.m. time slot were for illusionist David Blaine's magic special. We are just as fascinated as ever.

And why not? Illusions give us the thrill of realizing, even briefly, that we are actively interpreting and constructing our world, and that we can err in doing so. We can watch our own assumptions harden into fact and be broken, and learn about ourselves in the process.

Take the simple classic, the duck-rabbit illusion. In his article for *Nautilus*, Tom Vanderbilt uses it to open a window onto how we form beliefs, and how we get along with each other. In this and other stories from this issue, we learn that our perceptions are sometimes produced by our own brains and corrected by the world, not the other way around. In other words, that reality can be the greatest illusion of all.

Welcome to "Illusions."

—MS

"Numerous experiments have shown that the way we see the world is influenced by what we can do with it."

**JIM DAVIES**
"How Your Brain Gaslights You for Your Own Good" p. 52

# Illusions

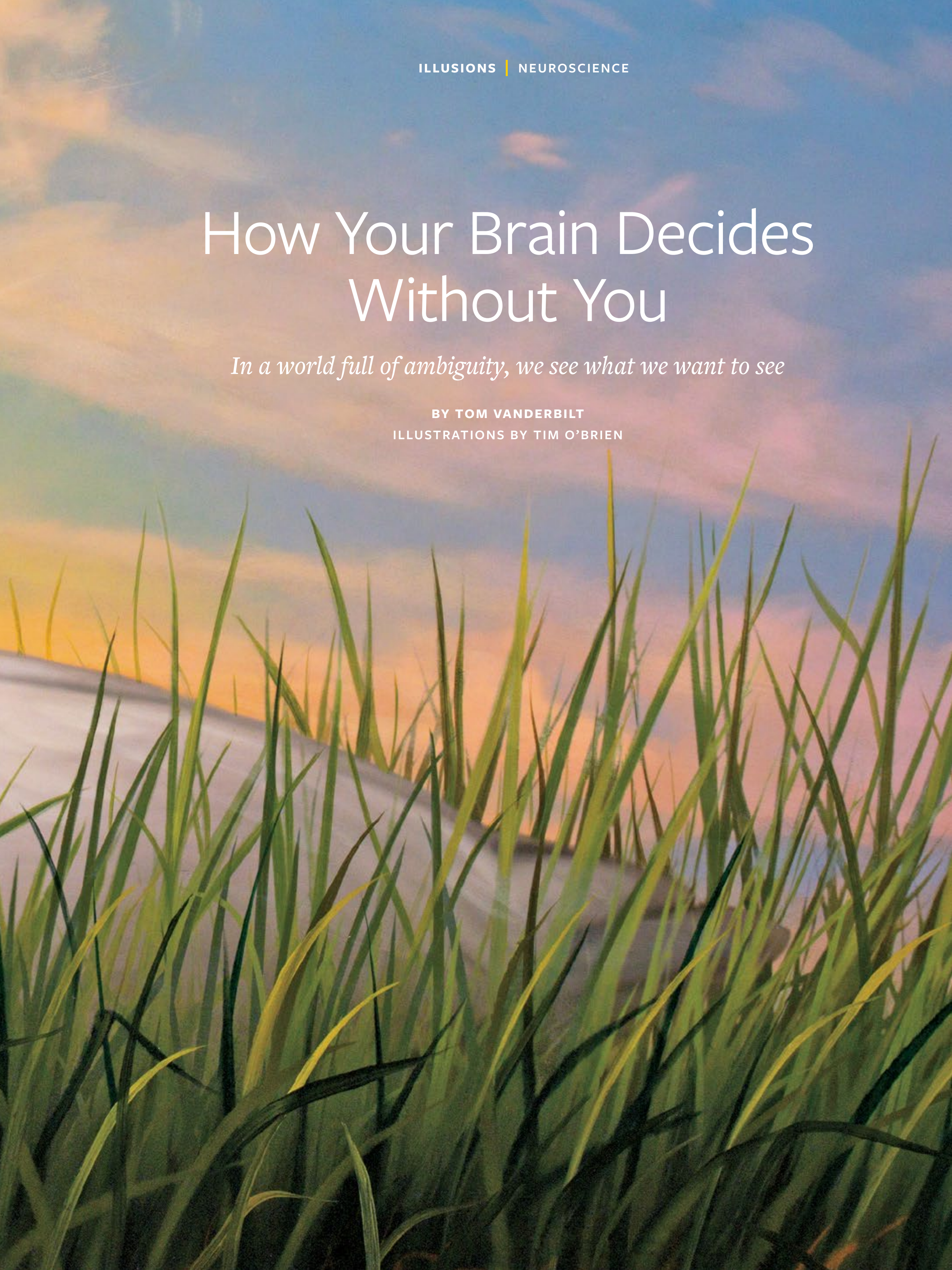
**REAL ENOUGH**

# How Your Brain Decides Without You

*In a world full of ambiguity, we see what we want to see*

BY TOM VANDERBILT

ILLUSIONS BY TIM O'BRIEN



**PRINCETON'S PALMER FIELD, 1951.** An autumn classic matching the unbeaten Tigers, with star tailback Dick Kazmaier—a gifted passer, runner, *and* punter who would capture a record number of votes to win the Heisman Trophy—against rival Dartmouth. Princeton prevailed over Big Green in the penalty-plagued game, but not without cost: Nearly a dozen players were injured, and Kazmaier himself sustained a broken nose and a concussion (yet still played a "token part"). It was a "rough game," *The New York Times* described, somewhat mildly, "that led to some recrimination from both camps." Each said the other played dirty.

The game not only made the sports pages, it made the *Journal of Abnormal and Social Psychology*. Shortly after the game, the psychologists Albert Hastorf and Hadley Cantril interviewed students and showed them film of the game. They wanted to know things like: "Which team do you feel started the rough play?" Responses were so biased in favor of each team that the researchers came to a rather startling conclusion: "The data here indicate there is no such 'thing' as a 'game' existing 'out there' in its own right which people merely 'observe.' " Everyone was seeing the game they wanted to see. But *how* were they doing this? They were, perhaps, an example of what Leon Festinger, the father of "cognitive dissonance," meant when he observed "that people cognize and interpret information to fit what they already believe."

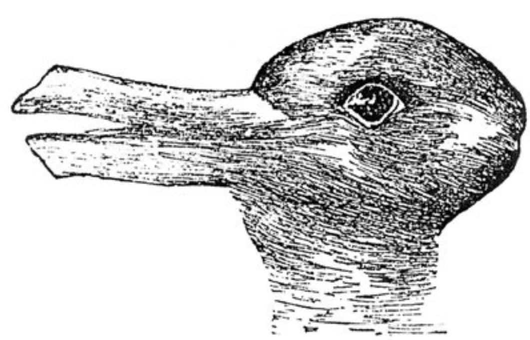
In watching and interpreting the game footage, the students were behaving similarly to children shown the famous duck-rabbit illusion, pictured on the right. When shown the illusion on Easter Sunday, more children see the rabbit, where on other Sundays they are more likely to see the duck.[1] The image itself allows both interpretations, and switching from seeing one to the other takes some effort. When I showed duck-rabbit to my 5-year-old daughter, and asked her what she saw, she replied: "A duck." When I asked her if she saw "anything else," she edged closer, forehead wrinkled. "Maybe there's another animal there?" I proffered, trying not to sound as if magnet school admission was on the line. Suddenly, a shimmer of awareness, and a smile. "A rabbit!"

I ought not to have felt bad. As an experiment by Allison Gopnik and colleagues showed, no child in a group of 3- to 5-year-old test subjects made the reversal (of a "vases-faces" illustration) on their own.[2] When a group of older—but still "naïve"—children were tested, one-third made the reversal. Most of the rest were able to see both when the ambiguity was mentioned. Interestingly, the ones who saw both on their own were those who had done better on an exercise testing "theory of mind"—in essence the ability to monitor our own mental state in relation to the world (for example, showing children a box of Crayons that turn out to contain candles, and then asking them to predict what another child would think is in the box).

And if *you* do not discern duck-rabbit at first, or any other figure reversal, there is no immediate cause for concern: Any number of studies show adults, who as the authors note "presumably have complex representational abilities," failing to make the switch. Nor is there any correct reading: While there is a slight rabbit tendency, there are plenty of duck people. Studies probing handedness as a cause have come up empty. My wife sees rabbit, I see duck. We are both lefties.

But while everyone, at some point, can be made to see duck-rabbit, there is one thing that no one can see: You cannot, no matter how hard you try, see both duck and rabbit at once.

**WHEN I PUT THE QUESTION** of whether we were living in a kind of metaphorical duck-rabbit world to Lisa Feldman Barrett, who heads the Interdisciplinary Affective Science Laboratory at Northeastern University,



**THE ORIGINAL** The duck-rabbit illusion was first illustrated by American psychologist Joseph Jastrow.

her answer was quick: "I don't even think it's necessarily metaphorical." The structure of the brain, she notes, is such that there are many more intrinsic connections between neurons than there are connections that bring sensory information from the world. From that incomplete picture, she says, the brain is "filling in the details, making sense out of ambiguous sensory input." The brain, she says, is an "inference generating organ." She describes an increasingly well-supported working hypothesis called predictive coding, according to which perceptions are driven by your own brain and corrected by input from the world. There would otherwise simply be too much sensory input to take in. "It's not efficient," she says. "The brain has to find other ways to work." So it constantly predicts. When "the sensory information that comes in does not match your prediction," she says, "you either change your prediction—or you change the sensory information that you receive."

This connection between sensory input on the one hand, and prediction and belief formation on the other hand, has been observed in the laboratory. In a study published in *Neuropsychologia*, when people were asked to think about whether a statement linking an object and a color—the banana is yellow is one example—was true, similar regions of the brain were activated when they simply were asked to perceive colors. As if thinking about the banana as yellow was the same as actually seeing yellow—a kind of re-perception, as is known to happen in memory recall (though the researchers also cautioned that "perception and knowledge representation are not the same phenomena").

We form our beliefs based on what comes to us from the world through the window of perception, but then those beliefs act like a lens, focusing on what they want to see. In a New York University (NYU) psychology laboratory earlier this year, a group of subjects watched a 45-second video clip of a violent struggle between a police officer and an unarmed civilian.[3] It was ambiguous as to whether the officer, in trying to handcuff the person resisting arrest, behaved improperly. Before seeing the video, the subjects were asked to express how much identification they felt with police officers as a group. The subjects, whose eye movements were being discretely monitored, were then asked to assign culpability. Not surprisingly, people who identified

Attention can be thought of as what you allow your eyes to look at.

JOSEPH JASTROW

# Your brain itself is in on the trick. The only dupe left in the room is you.

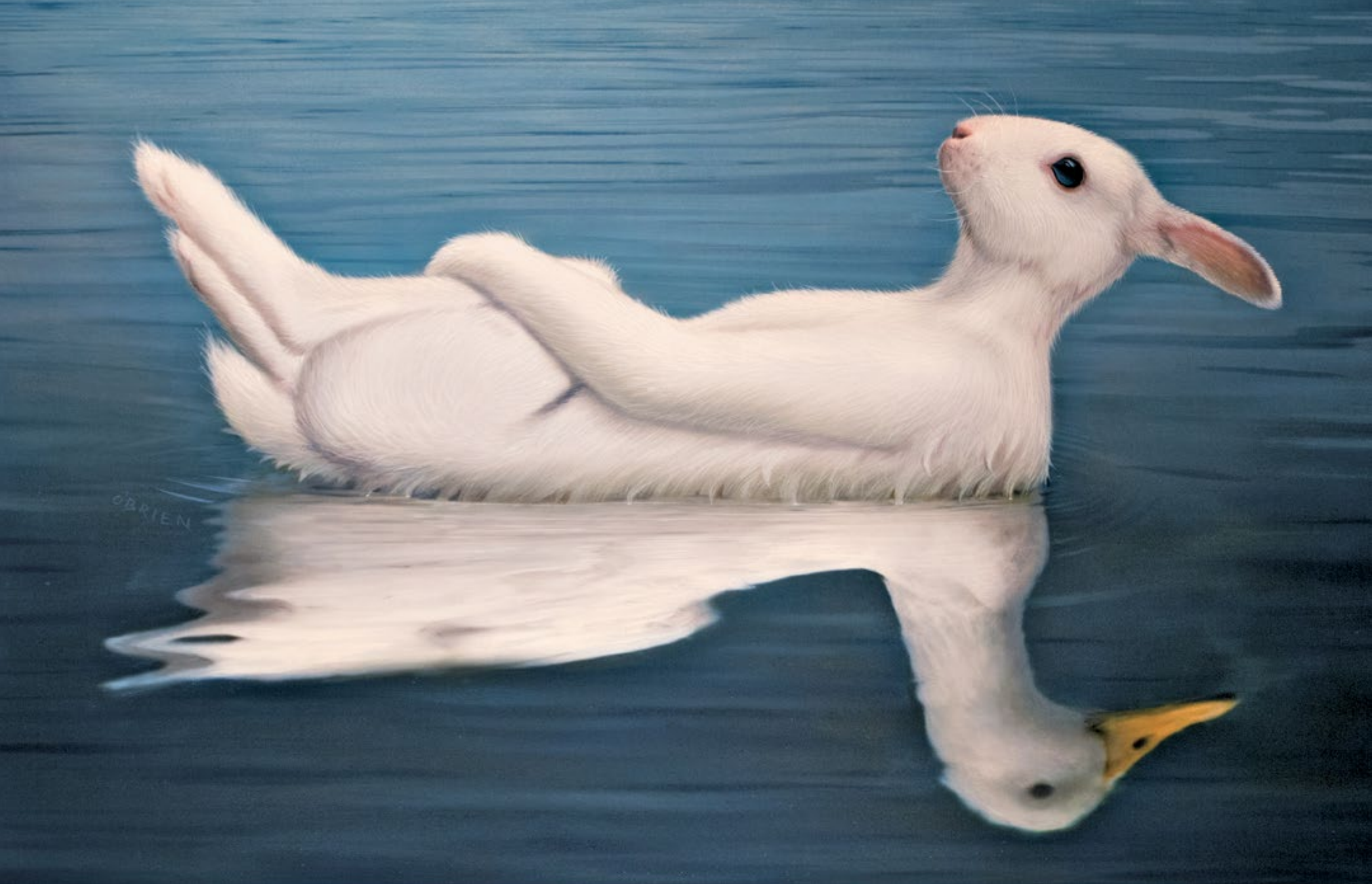
less strongly with police were more likely to call for stronger punishment. But that was only for people who often looked at the police officer during the video. For those who did not look as much at the officer, their punishment decision was the same whether they identified with police or not.

As Emily Balcetis, who directs NYU's Social Perception Action and Motivation Lab, and was a coauthor on the study, told me, we often think of decision making as the key locus of bias. But, she asks, "what aspects of cognition are preceding that big judgment?" Attention, she suggests, can "be thought of as what you allow your eyes to look at." In the police video, "your eye movements determine a completely different understanding of the facts of the case." People who made the stronger judgment against the police officer spent more time seeing him (and, per duck-rabbit, they were presumably not able to watch the officer and civilian *at the same time*). "If you feel he's not your guy," says Balcetis, "you watch him more. You look at the guy who might seem to you to pose a threat."

But what matters in making such assessments? This too, is fluid. Numerous studies have suggested a biased neural signature in subjects when they see images of people from their own racial in-group. But now tell subjects the people in those images have been assigned to a fictitious "team," to which they also belong. "In that first 100 milliseconds or so, we're presented with a rabbit-duck problem," says Jay Van Bavel, a professor of psychology at NYU. Are you looking at someone from your own team, or someone from a different race? In Van Bavel's study, suddenly it is the team members that are getting more positive neuronal activity, virtually rendering race invisible (almost as if, per duck-rabbit, we can only favor one interpretation at a time).[4]

We live in a world where "in some sense, almost everything we see can be construed in multiple ways," says Bavel. As a result, we are constantly choosing between duck and rabbit.

**WE ARE STUBBORN** about our decisions, too. In a study paying explicit homage to duck-rabbit, Balcetis and colleagues showed subjects a series of images depicting either "sea creatures" or "farm animals." Subjects were asked to encode each image; they would get positive or negative "points" for each correct identification. If they ended the game with a positive score, they would get jelly beans. Negative? "Partially liquefied canned beans." But the fix was in: The last image was an ambiguous horse-seal figure (with the seal a somewhat tougher see). To avoid consuming the nasty beans, subjects would have to see whichever image put them over the top. And, largely, they did. But what if subjects actually saw *both* images and simply reported only seeing the one that favored their own ends? They ran the experiment again, with a group of new subjects, this time with eye tracking. Those who had more motivation to see farm animals tended to look first at the box marked "farm animal" (where a click would encode their answer and send them to the next animal), and vice versa. The glance at the "correct" box (in their minds, anyway) was like a poker "tell," revealing their intention without conscious calculation. Their vision was primed to pick favorably.



But when the experiments faked a computer error and said, no, sorry, actually, it is the *sea creature* that will keep you from drinking liquid beans, most subjects, Balcetis says, stuck to their original, motivated perception—even in the light of the new motivation. “They cannot reinterpret this picture they have formed in their mind,” she says, “because in the process of trying to make meaning from this ambiguous thing in the first place removes the ambiguity from that.”

A recent study by Kara Federmeier and colleagues hints that something similar goes on in our formation of memories.[5] They considered the example of someone with a mistaken belief about a political candidate’s policy stance, like when most people incorrectly thought Michael Dukakis, not George Bush, had declared he would be the “education president.” Studying subjects’ brain activity via EEG, they found that people’s “memory signals” were much the same toward the incorrect information as they were toward the things they correctly remembered. Their interpretation of the event had hardened into truth.

This hardening can happen without our awareness. In a study published in *Pediatrics*, more than 1,700 parents in the United States were sent material from one of four sample campaigns designed to reduce “misperceptions” of the dangers of the MMR vaccine.[6] None of the campaigns, they reported, seemed to push the needle on parents’ intentions to vaccinate. For parents who were least likely to vaccinate to begin with, the material actually lowered their belief that MMR causes autism. But it also made them *less* likely to vaccinate. Showing people images of children with measles and mumps—the dangers of not vaccinating—only made people more likely to believe vaccines had dangerous side effects.

How exactly this hardening happens, and what might prompt someone to change their mind and reverse their duck-rabbit interpretation, is unclear. There is a long-lasting and ongoing debate over what exactly drives the figure reversal process.

One argument is that it is "bottom up." It could be that the neurons giving you the duck representation get tired, or "satiated," and suddenly the novel rabbit swims into view. Or there is something about the way the figure is drawn (the bill "pops out") or how it is presented that prompts the switch.

The opposing theory is "top down," suggesting something going on higher in the brain that predisposes us to make the switch: We have already learned about it, we are expecting it, we are actively looking for it. People instructed to *not* make reversals are less likely to, while asking people to do it faster increases the reversal rate.[7] Others argue that it is a hybrid model, challenging the distinction between top-down and bottom-up.[8]

Jürgen Kornmeier, of the Institute for Frontier Areas of Psychology and Mental Health in Freiburg, Germany, along with colleagues, has suggested one hybrid model, which questions the distinction between top-down and bottom-up. As Kornmeier described to me, even the earliest activity in the eyes and early visual systems betray top-down influence—and the information flow can by no means be assumed to be one-way. They suggest that even if we do not notice duck and rabbit, our brain may have actually registered the unreliability of the image subconsciously, and decided, in effect, not to spread the news. In this view, your brain itself is in on the trick. The only dupe left in the room is you.

None of which bodes well for the idea that policy or other debates can be solved by simply giving people accurate information. As research by Yale University law and psychology professor Dan Kahan has suggested, polarization does not happen with debates like climate change because one side is thinking more analytically, while the other wallows in unreasoned ignorance or heuristic biases.[9] Rather, those subjects who tested highest on measures like "cognitive reflection" and scientific literacy were also most likely to display what he calls "ideologically motivated cognition." They were paying the most attention, seeing the duck they knew was there.

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“WHY YOU KEEP DREAMING ABOUT BEING NAKED”
ILLUSTRATION BY **ASHLEY MACKENZIE**

# Stop Developing Drugs for the Cancer That Killed My Mother

*Funding drug development for rare cancers can hurt patients*

**BY ELIE DOLGIN**

THE SQUEAK in my mom's voice seemed strange, but not worrisome. When we spoke on the phone, she sounded like she had inhaled helium. An initial doctor's evaluation revealed nothing. And it wasn't until many weeks later, when she started having trouble swallowing one night at dinner, that alarm bells started to go off for our family.

She went to the drop-in health clinic on the small island in British Columbia where my family has a vacation home. The nurse looked at her swollen neck, felt a lump, and told her to rush to the ferry—she needed to get to the nearest hospital right away.

From there, she would have to move to a hospital in Vancouver, where my parents live. While my dad drove back to the vacation home to collect their clothes and other belongings, the results of my mother's biopsy came back. A tumor the size of a tennis ball had grown in her throat, and it was cancerous. I talked to my mother on the phone just minutes after she found out, and I've never heard her sound so scared and alone.

More tests brought on more bad news: The diagnosis was worse than we could have possibly imagined. It was anaplastic thyroid cancer, or ATC, and the tumor had metastasized to her lungs. I reached out to Robert Smallridge, an endocrinologist at the Mayo Clinic, for advice following my Mom's diagnosis, and he told me that ATC has a time from diagnosis to death that is unparalleled by any other malignancy—less than five months for the majority of patients. "Looking over the cancer landscape, this is about as bad as it gets," Smallridge said.

Less than two months later, on Sept. 10, 2012, my mother was dead. She would miss my October wedding. She would never meet my brother's son, her first grandchild, born that December.

I've since learned about a variety of drugs that are being developed to fight ATC—and I've decided that those development efforts should stop. Here's why.

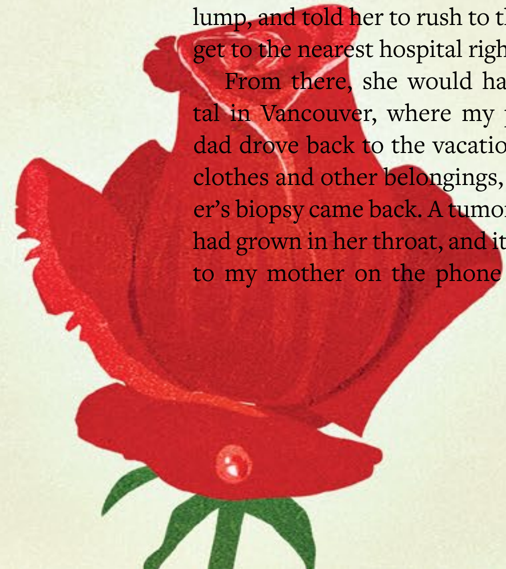

ILLUSTRATION BY SHOUT

**IN 2007, A CALIFORNIA COMPANY** called Oxigene decided to come to the rescue of patients afflicted with ATC. They launched an ambitious trial called FACT to test an experimental drug, Zybrestat—the first in a new class of compounds that target and destroy the blood vessels that feed cancer cells. Zybrestat had shown promise: In an earlier study, a 54-year-old man with ATC had received the drug, then lived for 15 years post-treatment before dying in 2012 of unrelated causes.

Yet doctors involved in the FACT trial struggled to find study subjects. And even when they identified interested patients, ATC's breakneck pace of growth meant that many would-be participants saw their cancers progress to the point that they were too sick to take part. "Time moves incredibly fast for these patients," says Peter Langecker, who served as president and CEO of Oxigene until May of this year.

Oxigene ultimately managed to recruit 80 patients—fewer than half the number it had hoped for, but still enough to make the FACT trial the largest randomized clinical study ever conducted on ATC. And although trial participants treated with Zybrestat lived longer than people in the control arm—with one-year survival rates of 27 percent and 9 percent, respectively—the trial was too small to robustly show whether this survival benefit could be chalked up to the drug or to chance.[1]

To meet the statistical threshold necessary to prove Zybrestat's potential, the U.S. Food and Drug Administration told Oxigene that the company would need to run a 300-patient trial. After having spent as much as $40 million for the FACT study, and estimating the high cost of a larger trial, Oxigene gave up on ATC and opted to pursue Zybrestat for the treatment of common ovarian cancer instead.

Oxigene's failure stemmed from ATC's two-hit combo—rarity and aggressiveness—which creates immense logistical hurdles to running clinical trials. "You're battling a mortal disease that is rapidly lethal and for which there is such a paucity of cases," says Julie Sosa, a surgical oncologist at the Duke Cancer Institute who led the FACT study.

As a result, trials become extremely expensive, sometimes requiring a combination of government and industry support. For example, the U.S.-Israeli firm Immune Pharmaceuticals is investigating a drug called crolibulin that kills ATC tumors in much the

> Scientists need to abandon the assumption that every medical challenge must be overcome by a direct attack.

same way as Zybrestat. Immune Pharmaceuticals is now recruiting patients in a trial on the drug—yet it's the U.S. government, through the National Institutes of Health (NIH), that is funding the study, and not investors hoping for a return on their dollar. Stephane Allard, the former chief medical officer of Immune, acknowledges that the company would not have pursued ATC without federal funding.

The call for more such funding has, by now, become a familiar refrain. "Patients and their families and friends need to raise money to help fund essential projects," wrote reporter Amy Dockser Marcus in the journal *Health Affairs*, after her mother died of a rare type of gallbladder cancer.[2] Funding was the main message from the Citizens' Committee for the Conquest of Cancer, which lobbied the U.S. government to launch the War on Cancer in 1971. And it remains the mantra today for organizations like the Leukemia & Lymphoma Society and the Multiple Myeloma Research Foundation.

All of which explains why the NIH has spent approximately $130 billion on cancer research since its "War" began—an investment made under the premise that diseases are beatable given enough money put into research and development. "I give up," are three words rarely uttered by doctors, scientists, and politicians, and so they continue to try.

But for rare, aggressive cancers like ATC, I argue that giving up is exactly what they should do.

**IN NOVEMBER 2014,** at the International Gynecologic Cancer Society Meeting in Australia, Oxigene presented results from a 107-person trial showing that

Zybrestat significantly reduced the rate of growth of ovarian tumors. This trial outcome moved the drug one step closer to market approval for women with ovarian cancer. It also placed the drug within the reach of ATC patients. That's because of a practice called off-label drug prescriptions: Doctors can choose to prescribe an FDA-approved cancer drug to a patient suffering from a cancer other than the one for which the drug was approved.

There's evidence that off-label drug repositioning can help ATC patients. Three independent clinical teams recently published case reports documenting dramatic responses among ATC patients treated with the kidney and gastrointestinal cancer drug Sutent.[3,4,5] In another study, more than a third of ATC patients lived one year or longer when given the leukemia drug Gleevec—a survival statistic that might not sound impressive, but it's often better than what's observed with the chemotherapy drugs currently given to people with ATC.[6]

What's more, off-label prescriptions have been aided by genomic medicine. For example, oncologists last year reported the case of a man with ATC who received a skin cancer drug, called Zelboraf, after a DNA test revealed a mutation indicating that he'd be a likely responder. One month post-treatment, his metastatic lung and bone lesions had practically vanished.[7] With genetic profiling, doctors can now "distribute patients with anaplastic thyroid cancer to the therapy that makes sense for them," says Nikhil Wagle, a cancer geneticist at the Dana-Farber Cancer Institute who successfully treated a woman with ATC with the help of DNA sequencing and another off-label cancer drug.[8]

In contrast, my mother received an old chemotherapy drug, combined with radiation. Her therapy wasn't tailored to her. It was the same tried-and-failed treatment that patients with ATC have received for decades, while doctors hold out for an ATC-specific drug.

The enormous amount of money required to bring drugs for ATC and other rare diseases through clinical trials could be used to pursue therapies for more common cancers, with trials that are more likely to succeed, resulting in approved drugs. Once on pharmacy shelves, doctors could prescribe these medicines off-label for patients with no other promising drug options—patients like my mother.

Scientists need to abandon the assumption that every medical challenge must be overcome by a direct attack. An easier, albeit imperfect, route to improved patient outcomes may be available today with medicine's existing arsenal. Drugs approved for other cancers might have helped my mother. We didn't know it then, but she wasn't as alone with her diagnosis as she sounded on the phone.

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# The Illusion Machine That Teaches Us How We See

*A mathematician is using computers to manufacture award-winning illusions*

**BY ERICA KLARREICH**

**THE MAN SPRANG ONSTAGE** dressed as a miner, complete with headlamp and pickaxe. After swinging the axe a few times, he proclaimed to the audience that he had discovered a "supermagnet"—a substance so strong it could attract even wood. A video screen above him appeared to prove him right: It showed wooden balls rolling up four ramps, seemingly unbound by gravity.

The man was not in fact a miner, but a mathematician—Kokichi Sugihara, of Meiji University in Tokyo, Japan. He was competing in the 2010 finals of the annual Best Illusion of the Year Contest in Naples, Florida. And, as the video went on to show, the balls were not really rolling uphill. A look at the back of the ramp structure showed that pillars that from the front had seemed vertical were in truth anything but, and that the ramps were pointing downhill, not uphill. The demonstration (which won that year's top prize) was an illusion, and Sugihara had designed it together with an unusual collaborator: a computer program.

Sugihara didn't originally set out to become a master illusionist. As a young mathematician in 1980, he was interested in robot vision and computer-assisted design. With those applications in mind, he created a computer program that could take a line drawing of a polygonal shape and come up with a list of three-dimensional objects that would create that drawing when projected onto a flat plane—akin to working backward from a shadow to the possible objects that could have cast it. To test his program, Sugihara fed it drawings of impossible-seeming objects, like M.C. Escher's endless loop of stairs. He expected the program to reject the drawings, but to his surprise, in some cases it claimed to have found a solution: a three-dimensional object that looked just like the drawing. "I thought my software was incorrect," Sugihara said.

On closer inspection, he realized that what was incorrect was his assumption that these "impossible" two-dimensional objects couldn't exist in the three-dimensional world. He started making paper models of his program's designs, and gradually, the robot and design applications fell by the wayside—his program wasn't ideally suited to them, he discovered. Instead, he dedicated himself to exploring the strange constructions that came so easily to his program, and that appeared so baffling to human viewers. He had built an illusion machine.

Over the 34 years since then, Sugihara has used his

ILLUSTRATION BY KOKICHI SUGIHARA

illusion machine to create and build more than 100 illusions: impossible objects such as a solid model of Escher's staircase, and intuition-defying motions such as balls rolling uphill. "Sugihara has come up with systematic ways of playing with what happens when the rules of the vision system fall apart," said Arthur Shapiro, a neuroscientist at American University in Washington, D.C. Part scientist and part artist, his work is helping to elucidate the basic mathematics underlying how our brains construct our world.

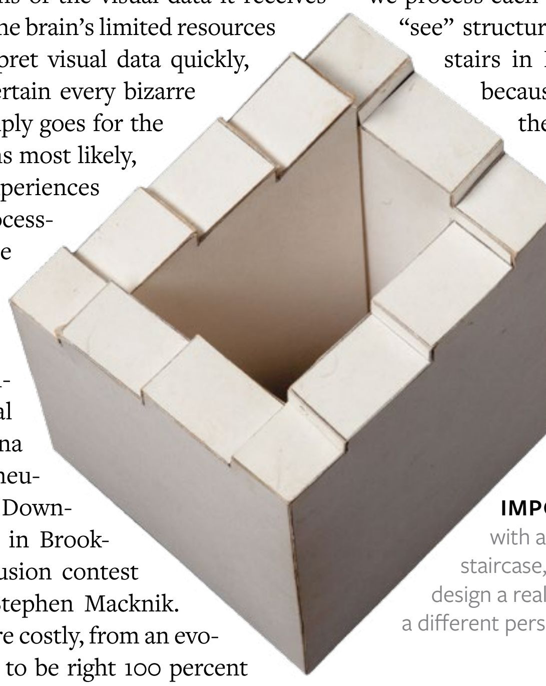
**THE HUMAN BRAIN ROUTINELY** throws away many possible interpretations of the visual data it receives from the eyes. Given the brain's limited resources and its need to interpret visual data quickly, it can't afford to entertain every bizarre interpretation—it simply goes for the explanation that seems most likely, based on its past experiences and built-in visual processing machinery. For the most part—though not always—this explanation comes close enough to reality for all practical purposes, says Susana Martinez-Conde, a neuroscientist at SUNY Downstate Medical Center in Brooklyn, who runs the illusion contest with her colleague, Stephen Macknik. "It would be much more costly, from an evolutionary perspective, to be right 100 percent of the time."

Sugihara believes that there's a simple reason why his illusions appear so baffling: We are primed to perceive right angles, even when they do not exist. Many of the most compelling impossible pictures involve structures in which there are only three different directions of lines. When that happens, we seem to have an irresistible urge to perceive the three directions as mutually perpendicular wherever they meet.

Sugihara has tested this hypothesis by instructing his program to select the three-dimensional interpretation with the most right angles. Usually, he said, this makes the computer pick the same solid that humans perceive, supporting the hypothesis. When there is more than one solid with the maximal number of right angles, Sugihara suspects that the human visual system uses lighting cues to decide among them. The visual system tends to interpret brighter surfaces as facing upward and darker surfaces as facing downward, he says. Sugihara hopes eventually to build a module onto his program to test this guess.

Once we have made a right-angle interpretation, says Macknik, we tend to hang on to it even if it doesn't make sense on a global scale. That's because we process each bit of an image locally, leading us to "see" structures that are impossible. "We see the stairs in Escher's staircase going up forever because locally, from one stair to the next, the angles are approximately correct," he said. "There are enough small errors, which we don't detect at the local level, to add up to a global impossibility."

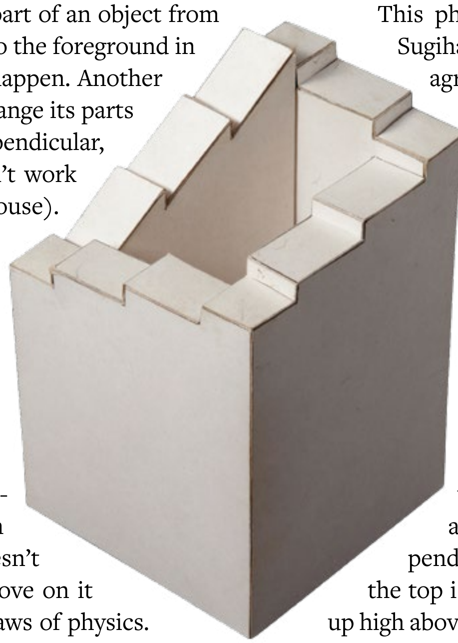
Sugihara's ability to systematically manufacture illusions presents a new opportunity to probe our visual system. Another visual theory many psychologists entertain, Sugihara said, is that the vision system chooses the most symmetric possible interpretation of what it sees. He has begun to work with Akiyoshi Kitaoka, a psychologist who studies illusions at Ritsumeikan University in Kyoto, Japan, to figure out which of Sugihara's illusions would best distinguish between this theory and the right-angle theory. The work should help researchers understand what priority we give to various visual shortcuts. As a rule, Martinez-Conde says, the lower down in the visual hierarchy an illusion gets processed, the harder it is to dispel. Depth illusions,



**IMPOSSIBLE MADE REAL** Starting with a flat drawing of Escher's impossible staircase, Sugihara used his illusion machine to design a real three-dimensional model. Seen from a different perspective (p. 50), the trick is clear.

which happen at a middle level of visual processing and describe much of Sugihara's work, are "very resilient," she says.

**SUGIHARA'S PROLIFIC OUTPUT RELIES** not just on his program, but also on the impossible drawings that are its raw material. One tool he frequently uses to create these drawings is to move part of an object from the background of the picture to the foreground in a way that couldn't physically happen. Another is to cut up a drawing and rearrange its parts so that the angles still seem perpendicular, but the new picture just doesn't work in the real world (see Chophouse). Using these and other simple tools, he has created a diverse gallery of impossible drawings. Most of these can't be realized as three-dimensional objects, but Sugihara's program has identified some that can.



In recent years, he has added impossible motions to his repertoire—constructions in which the three-dimensional solid doesn't look impossible, but objects move on it in ways that seem to defy the laws of physics. Sugihara's program produces solids with straight lines and flat faces. Analyzing motion on such a solid is simple, and Sugihara has added a module to his program to do just that. To create the prize-winning illusion of balls rolling uphill, for example, Sugihara simply drew a sketch of the ramp apparatus, then instructed his program to come up with all the three-dimensional interpretations of the picture and identify the ones in which balls would roll "uphill."

When we look at one of these impossible objects or motions, our cognitive realization that something is wrong isn't strong enough to override the brain's knee-jerk interpretation of the three-dimensional geometry. "Interpretation of images of three-dimensional solids can't be controlled by the logical part of the brain," Sugihara says.

This phenomenon is readily apparent in Sugihara's latest illusion, which he has agreed to unveil here (see Folding Ladder). In it, a straight rod moves through the rungs of a folded ladder-like structure in a way that should be impossible if the rod can't bend. To create the illusion, Sugihara sketched the ladder, then ran the drawing through his program and chose the three-dimensional interpretation that was most different from the natural human interpretation. Our right angle preference makes us visualize the top side of the ladder as flat, since that would make it perpendicular to all the support rungs. But the top isn't flat: Several of the rungs come up high above the horizontal plane, enabling the rod to fit through them in ways that look impossible.

**SUGIHARA'S PROGRAM MIGHT GIVE** you the idea that sophisticated computer vision systems could be created that are free of our propensity to be hoodwinked. However, it's unlikely that any computer program could see as well as humans without going through some sort of evolutionary process, said Dale Purves, a neuroscientist at Duke University in Durham,

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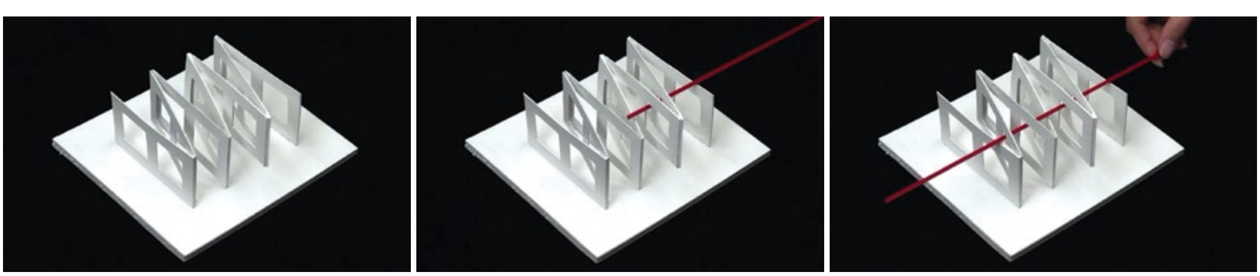
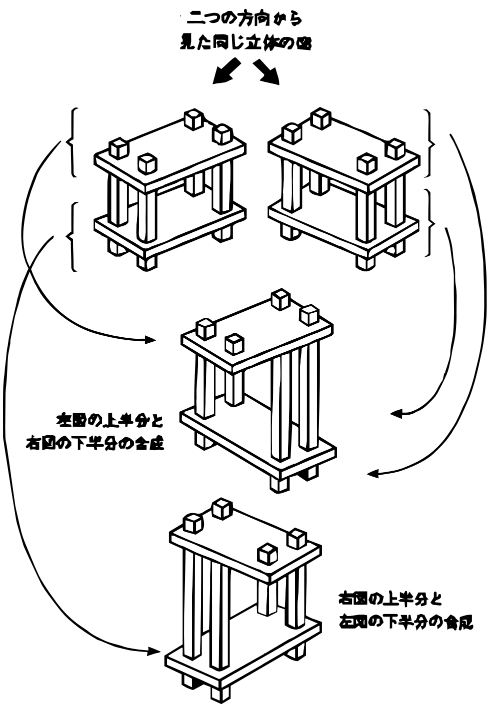


North Carolina. "Our vision has benefitted from millions or billions of years of evolution, depending on how you want to look at it," he said. "I don't think a machine will come close to working well until its connectivity is established by evolution, rather than the logic of engineers."

And if robots do learn to see through evolution, they may inevitably be subject to the same illusions humans are. Beau Lotto, a neuroscientist at University College London, and David Corney, of Robert Gordon University in Aberdeen, Scotland, created robots that learned through trial and error to predict the shades of gray in synthetic nature scenes. Like humans, the robots were fooled by "White's illusion," in which identical shades of gray seem lighter or darker, depending on whether they are next to black or white stripes. It is also possible, though, that a computer vision system honed by evolution could be combined with programs such as Sugihara's to offer the best of both worlds, Macknik says. "I have every confidence that there will eventually be things computer vision systems can do better than humans."

For now, programs like Sugihara's remain much less broadly effective than human vision. But they are unencumbered by our predilection to be fooled—something Sugihara plans to exploit to the fullest extent. After all, illusions aren't just a professional interest for him, he says: "It's my pleasure to make other people surprised."

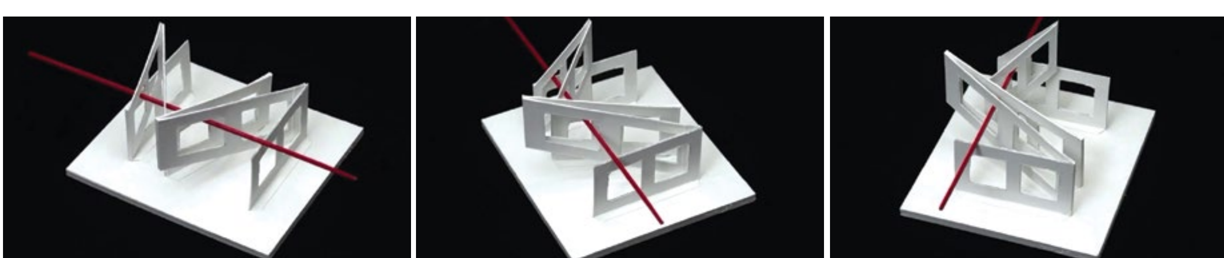
**ERICA KLARREICH** is a mathematics and science writer based in Berkeley, California. Her work has appeared in the 2010 and 2011 volumes of *The Best Writing on Mathematics.*




**CHOPHOUSE** The two top figures are cut in half and reconnected in new ways, creating two "impossible" drawings.

KOKICHI SUGIHARA

**FOLDING LADDER** A brand-new illusion by Sugihara, revealed in this article for the first time, shows a rod moving in seemingly impossible ways through the openings of a folded ladder (bottom of p.50). The unusual geometry that makes this possible is revealed below.



# How Your Brain Gaslights You for Your Own Good

*Evolution favors the fooled*

**BY JIM DAVIES**

RUNNERS CAN TELL YOU that sometimes the last mile of a run seems to feel dramatically longer than the first. This perceptual distortion isn't limited to brains addled by exercise—it's a consistent feature of our minds.

When we look at the world, it certainly feels like we're seeing things as they really are, our senses measuring reality in an objective way. But numerous experiments have shown that the way we see the world is influenced by what we can do with it.

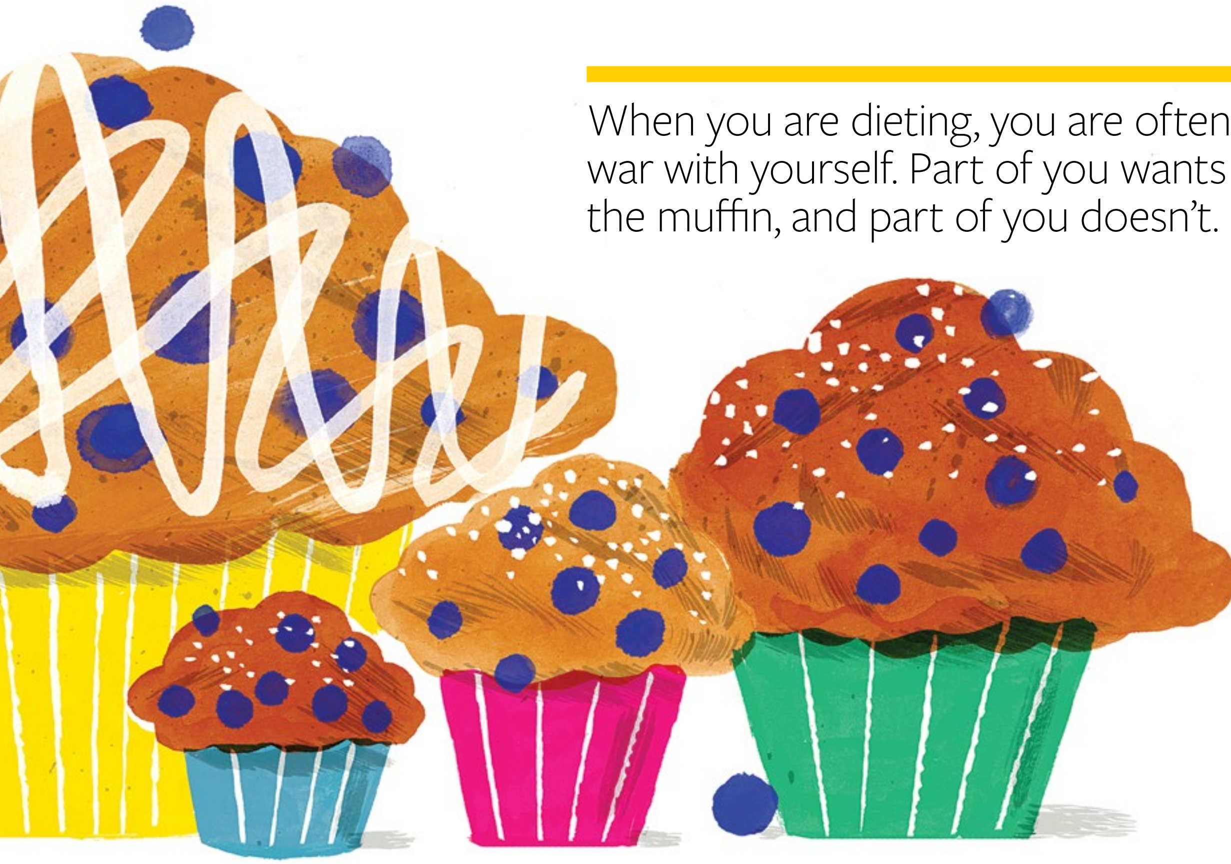
This way of thinking was pioneered by psychologist James Gibson, who came up with the idea of "affordances": A ball affords picking up, and a hallway affords walking along it. When we look at a button, we perceive the affordance of pressing it. These are not optical illusions, as such, but changes in how we see the world according to what we want and can do. Here are some fascinating examples.

The perceived height of a balcony is increased if you are afraid of falling. Hills look steeper if you're elderly, tired, or wearing a heavy backpack; they look less steep after you consume a high-calorie drink. Because descending a hill is more dangerous than going up it, hills look steeper from the top than from the bottom. That's also why kids on the ground might think a tree is not too high, but after they climb it, they're not so sure.

Hungry men prefer the looks of women with more weight on them, while men who are full prefer thinner women. We can speculate on the reasons for this. It might be that hunger is associated with lean eating times, and during those times, someone with enough resources to put on weight might be at an advantage to someone who's thinner. This is supported by the finding that in poor areas, cultural ideals of feminine beauty are heavier than those in more affluent cultures, where the ideal woman is relatively thinner.

Food and drinks also look different according to our internal states. Thirsty people see bottles of water as being closer than people who aren't thirsty. Your need for water makes the bottle look closer to encourage

ILLUSTRATION BY MIKE REDDY



When you are dieting, you are often at war with yourself. Part of you wants the muffin, and part of you doesn't.

you to reach for it.

In general, we see desirable objects as closer. Dieters see muffins as being bigger than non-dieters do. This raises an interesting question: If people *want* to diet, then shouldn't the food look smaller, and *less* appealing? The answer could be that the changes in perception work according to our subconscious drives, and less by our explicit goals. When you are dieting, you are often at war with yourself. Part of you wants the muffin, and part of you doesn't. Looks like the part that wants the muffin has more control over your perception.

Threatening things, such as spiders, are also perceived to be closer, and also larger and faster. At first glance, these two findings may seem mysterious, even contradictory: Why would frightening things *and* desirable things look closer? Certainly your mind isn't encouraging you to reach out and touch the spider like it is in the muffin case. A desirable thing appearing closer encourages you to try to get it. A frightening thing appearing closer makes an already dangerous situation appear more urgent, encouraging you to get away. Hope and fear are compelling. It's the middle ground that's boring. So even though both good and bad things look closer, it makes sense because closeness encourages different behaviors in these cases.

Physiological states, such as low blood glucose, and social states, such as what kinds of friends are nearby, affect our perceptions of the world. We have evolved to manage the resources we have, and our perceptual system helps us do that by changing our perceptions depending on the available resources. At the end of a run, your energy stores are depleted, and your mind makes the last mile look longer to discourage you from wasting any more energy.

But it's an illusion. A mile is a mile, no matter how tired you are.

**JIM DAVIES** is an associate professor at Carleton University and author of *Riveted: The Science of Why Jokes Make Us Laugh, Movies Make Us Cry, and Religion Makes Us Feel One with the Universe.*

# When Bad Things Happen in Slow Motion

*Is there more to our experience of time than the foibles of memory?*

**BY IVAN AMATO**

NOTHING FOCUSES THE MIND like a moment of peril. John Hockenberry, the heavily-decorated journalist and commentator, had one of those nearly four decades ago. Yet it has never left him, and it always plays out in his memory, as he puts it, "in super slo-mo."

"About 38 years ago, I was on a road in Pennsylvania. I was sleeping in the back of a car. I woke up. The driver of the car was also asleep," Hockenberry recounted from his wheelchair in early June at this year's World Science Festival in New York as he opened up a panel discussion on time perception. "The car was veering off the road. The passenger next to her reached over very slowly, it seemed, grabbed the wheel, and pulled that wheel as hard as she could ... and the car veers to the right. And very slowly we hit the guardrail, the car flips into the air, and I can feel in my gut that all of life is going to change."

Retired fire chief Richard Gasaway refers to this apparent slowing down of time in tense situations as tachypsychia, which roughly translates as "fast mind." "This phenomenon afflicts many first responders," Gasaway claims, based on hundreds of interviews he has conducted for his research, blog, and speaking engagements on "situational awareness." Bolstered also by what he judges to be personal experiences of tachypsychia, Gasaway has come to consider it as a sometime component of the overall stress response. For first responders, the phenomenon is dangerous, he says, because it can warp situational awareness and decision-making processes.

But is tachypsychia real, or an illusion? David Eagleman of the Baylor College of Medicine set out to answer this question with a test. Together with his colleagues, he developed a wristwatch-like "perceptual chronometer" that alternately displays red digits and their negative images (a red background with unlit pixels in the shape of the digits) at rates faster than a threshold at which the toggling images fuse into what appears to be a uniform patch. This threshold is

ILLUSTRATION BY NOMA BAR

called a critical fusion frequency, or CFF. Eagleman hypothesized that if he could terrify people while they were looking at the chronometer, then their CFF would spike, they would switch into slow-motion perception mode, and they would suddenly be able to discern the digits on the chronometer.

To carry out the tests, Eagleman took 20 people to the Zero Gravity Thrill Amusement Park in Dallas. There he strapped them into the Suspended Catch Air Device of the 16-story-high "Nothin' but Net" ride, in which the chronometer-wearing participants would free fall 31 meters before landing in a net. The participants were tasked to keep an eye on their chronometer during their jaw-clenching, 2.5-second drop. One participant squeezed her eyes shut the entire time and so she yielded no data.

The data from the other participants made it clear: No one could discern the digits during their free falls. But, when asked after the fact to estimate the duration of their own falls (by replaying their experience in their minds and with a stopwatch in hand), the participants recorded, on average, that their drop lasted about a third longer than the drops of others they had witnessed as at-ease spectators. Eagleman concluded the subjective experience of time slowing down under harrowing circumstances is an artifact of memory, not an actual trait of real-time perception. In short, time was not slowing down for anybody.[1]

"Under normal circumstances, most of the stuff flowing through your sensorium, you don't remember," Eagleman explained. "What happens in a life-threatening situation is that everything gets written down. Everything is retained in memory." Because the brain is not used to memory of such density, he continued, "the brain's interpretation is that the whole thing must have gone more slowly."

But what if a test subject was affected, not by a moment of peril, but by some mental or cognitive dysfunction? Eagleman and colleagues at Baylor and the Harris County Psychiatric Center in Houston asked people with schizophrenia and those in a control group to report how many stimuli, such as letters, pictures, and faces, they could perceive as they watched a series of rapidly flashing screens. The results suggested, Eagleman says, "a single flash that to you lasts 100 milliseconds, might seem like 120 milliseconds to someone with schizophrenia." This 20 percent difference at the sensory level, he speculates, could belie temporal dysfunction at higher cognitive levels. For example, it could make it difficult to map the internal dialog one routinely hears in one's "mind's ear" onto oneself. In such a situation, Eagleman suggests, the frequent report by schizophrenics of hearing voices might amount to a rational interpretation of their subjective, temporally-dysfunctional experience.[2]

Swordfish essentially are visitors from another temporal dimension.

With evidence in hand of at least a limited spread of CFFs among us, humans join a much broader spectrum ranging across the animal kingdom, according to a cross-species analysis published recently in the journal *Animal Behaviour*. The CFF for people is, on average, 60 flickers per second, which is why televisions' refresh rates are at or above that frequency. In the animal kingdom, it runs from as low as 6.7 for a cane toad, to 108 for a ground squirrel, to 240 for a common blowfly. Generally speaking, the faster an animal's metabolism or the smaller its size, the higher its CFF.[3]

These differing CFF values seem to offer some fascinating explanatory power. No wonder it is hard to kill a fly with your murderous swatting hand. With a CFF of 240, the fly might well see your approaching hand as though it were muscling through molasses. And how about those aeronautical stunts by birds flying through thickets of vegetation? With CFFs around 100, they are likely visually sampling their surroundings at superhuman rates that allow for faster mid-air adjustments.

There is some evidence that this temporal dimension could be critical to the planet's ecological competitions: "Time perception might constitute an important and overlooked dimension of niche differentiation," says zoologist Andrew Jackson of Trinity College Dublin, one of the authors of the *Animal*

*Behaviour* article. When cold-blooded swordfish dive in pursuit of squid, for one, they upshift their CFF by surging warm blood to their eyes. "This presumably gives them a huge advantage when they dive to hunt relatively sluggish squid in the colder waters below," says Jackson. "In this way, swordfish essentially are visitors from another temporal dimension ... The squid probably stand little chance of survival." People can't get away with this eye and brain warming tactic to crank their CFF; it would mean heating up tissue into high-fever territory where proteins unravel and cells start to not care about living anymore.

That said, Jackson believes that it may be possible that we all have slightly different CFFs, which could help explain details of our personality, talents, choices, and perceptions. "Should a person have a higher CFF than their group mates, then they would effectively have the potential to react to events in the world that would to their group mates seem impossibly fast," Jackson said. "I kind of wonder if this might explain the feeling sometimes when you are playing sports like soccer and you feel completely on top of your game, and able to breeze past your opponent with a feeling that the game feels almost slow to you."

On Jackson's research to-do list are studies that might characterize natural variations in flicker fusion rates among individuals and how much an individual's CFF might vary under many different circumstances. "Where it gets really interesting," Jackson adds, "is whether there are consequences for these differences in our everyday life."

Jackson is in the midst of writing up a grant application for work that would dig into these questions. If the money comes through, he says, he would love to recruit fast-action aficionados of Bruce Lee and LeBron James caliber for whom it is conceivable that above-average CFF rates could play into their magnificent physical feats. Regarding possible CFF-cognition connections, Jackson says he would be interested to see whether "low-CFF individuals" might be more apt to miss subtle but important cues in, say, facial expressions. And there is one more thing Jackson would like to explore: whether it might be possible to train people to increase their CFF rate with the intention of improving sporting performance or to help treat temporality-based dysfunctions.

Researchers warn that the data in hand is too scant to conclude much about CFFs in humans for the time being, or even to say with certainty what the connection is between CFFs and subjective time perception. But the variability of CFFs among animals and those with mental disorders, together with our subjective experience of time, leave us with an interesting question to ponder: Are there people who, like the swordfish, live in another temporal dimension?

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# 20

**IN 2010, IBM ASKED** over 1,000 CEOs and global leaders what they valued most in other leaders. Humility came in eighth and openness fifth. Integrity seems important in a leader—and it was, but not enough to be in first place. That honor went to creativity. The then-CEO of IBM declared that "today, creativity itself has been elevated to a leadership style."

But in science and art, the refrain is familiar and old. Einstein famously argued that imagination was more important than knowledge, and some modern researchers have argued that creativity is the bright line between people and machines. The artist Man Ray called creativity divine (whereas reproduction was only human), an idea that appears in cosmogonies both modern and ancient.

And what is evolution if not a creative force? Don't cells themselves lead lives as multifarious as ours? The message seems clear for both people and nature: Creativity rules.

Welcome to "Creativity."

—MS

"The guitarist's recovery epitomizes the ability of the brain to improvise—to compensate for damage by wiring new connections."

**BRIAN GALLAGHER**
"Brian Damage Saved His Music" p. 84

# Creativity

## SWIMMING IN POSSIBILITY

# The Strange Inevitability of Evolution

*Good solutions to biology's problems are astonishingly plentiful*

**BY PHILIP BALL**

**IS THE NATURAL WORLD CREATIVE?** Just take a look around it. Look at the brilliant plumage of tropical birds, the diverse patterns and shapes of leaves, the cunning stratagems of microbes, the dazzling profusion of climbing, crawling, flying, swimming things. Look at the "grandeur" of life, the "endless forms most beautiful and most wonderful," as Darwin put it. Isn't that enough to persuade you?

Ah, but isn't all this wonder simply the product of the blind fumbling of Darwinian evolution, that mindless machine which takes random variation and sieves it by natural selection? Well, not quite. You don't have to be a benighted creationist, nor even a believer in divine providence, to argue that Darwin's astonishing theory doesn't fully explain why nature is so marvelously, endlessly inventive. "Darwin's theory surely is the most important intellectual achievement of his time, perhaps of all time," says evolutionary biologist Andreas Wagner of the University of Zurich. "But the biggest mystery about evolution eluded his theory. And he couldn't even get close to solving it."

What Wagner is talking about is how evolution innovates: as he puts it, "how the living world creates." Natural selection supplies an incredibly powerful way of pruning variation into effective solutions to the challenges of the environment. But it can't explain where all that variation came from. As the biologist Hugo de Vries wrote in 1905, "natural selection may explain the *survival* of the fittest, but it cannot explain the *arrival* of the fittest." Over the past several years, Wagner and a handful of others have been starting to understand the origins of evolutionary innovation. Thanks to their findings so far, we can now see not only *how* Darwinian evolution works but *why* it works: what makes it possible.

A popular misconception is that all it takes for evolution to do something new is a random mutation of a gene—a mistake made as the gene is copied from one generation to the next, say. Most such mutations make things worse—the trait encoded by the gene is less

ILLUSTRATIONS BY JON HAN

effective for survival—and some are simply fatal. But once in a blue moon (the argument goes) a mutation will enhance the trait, and the greater survival prospects of the lucky recipient will spread that beneficial mutation through the population.

The trouble is that traits don't in general map so neatly onto genes: They arise from interactions between many genes that regulate one another's activity in complex networks, or "gene circuits." No matter, you might think: Evolution has plenty of time, and it will find the "good" gene circuits eventually. But the math says otherwise.

Take, for example, the discovery within the field of evolutionary developmental biology that the different body plans of many complex organisms, including us, arise not from different genes but from different networks of gene interaction and expression in the same basic circuit, called the Hox gene circuit. To get from a snake to a human, you don't need a bunch of completely different genes, but just a different pattern of wiring in essentially the same kind of Hox gene circuit. For these two vertebrates there are around 40 genes in the circuit. If you take account of the different ways that these genes might regulate one another (for example, by activation or suppression), you find that the number of possible circuits is more than $10^{700}$. That's a lot, lot more than the number of fundamental particles in the observable universe. What, then, are the chances of evolution finding its way blindly to the viable "snake" or "human" traits (or phenotypes) for the Hox gene circuit? How on earth did evolution manage to rewire the Hox network of a Cambrian fish to create us?

The galaxy of gene circuits isn't the only mind-bogglingly immense terrain that evolution has to navigate in order to innovate. The same issues apply, for example, to metabolic networks. Organisms have had to find ways of getting their energy from whatever fuel happens to be on hand—typically the metabolisms of microorganisms run on compounds such as glucose, ethanol, or citrate. Ideally, their metabolic machinery of enzymes would run on more than just one of these, so that they'd have more options for survival. But how easy is it to adapt to other fuels? Even for a relatively small list of common metabolic fuels, the number of possible metabolisms of this sort is again astronomical.

The same explosion of combinatorial options happens for proteins, which are molecules made up of many tens to hundreds of amino acids bound together in chains and folded up into particular molecular shapes. There are 20 different amino acids found in natural proteins, and for proteins just 100 amino acids long (which are small ones) the number of permutations is $10^{130}$. Yet the 4 billion years of evolution so far have provided only enough time to create around $10^{50}$ different proteins. So how on earth has it managed to find ones that work?

Finally there's RNA. This molecule, once considered the mere go-between in converting a sequence of chemical building blocks in a gene (called base pairs) into a sequence of amino acids in a protein that catalyses a biochemical reaction, is now afforded much more status. For one thing, because RNA molecules can imitate both genes, by encoding information in a sequence, and proteins, by folding up into shapes that act as chemical catalysts, RNA is the best candidate for the multi-tasking molecules that orchestrated the earliest life. What's more, we now know that RNA molecules are important regulators of gene activity: Some genes interact with others via the RNA molecules they encode, which can act as switches to turn the expression of other genes up or down. Yet evolutionary innovation with RNA also faces an absurd profusion of combinatorial choices.

In all these cases the questions are the same, and point to, as Wagner puts it, a "dirty secret" behind the success of the so-called modern synthesis of Darwinian evolutionary theory and genetics. How does evolution find workable solutions when it lacks the means to explore even a small fraction of the options? And how does evolution find its way from an existing solution to a viable new one—how does it create? The answer is, at least in part, a simple one: It's easier than it looks. But only because the landscape that the evolutionary process explores has a remarkable structure, and one that neither Darwin nor his successors who merged Darwinism with genetics had anticipated.

## Casting a billion nets

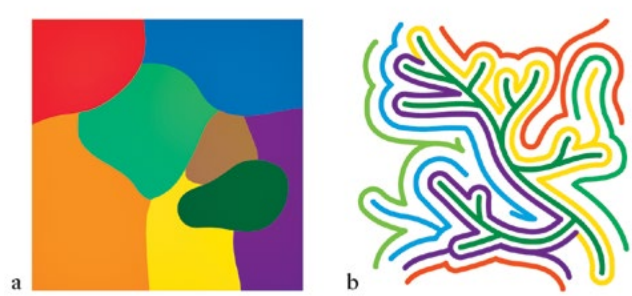
One of the first people to begin exploring how evolution creates was the Austrian scientist Peter Schuster. (He is one of those researchers whom one has to label simply "scientist" because it is impossible to decide if he is a physicist, chemist, or biologist.) Because of his interest in the possibility that life began with RNA—in the so-called RNA world—in the 1970s Schuster began to explore what RNAs could do. To act as a catalyst, an RNA molecule needs to fold into the right shape. As with a protein, this shape is determined by the molecule's sequence of building blocks. In effect this is a genotype-to-phenotype question, with the genotype being the RNA's sequence and the phenotype its folded shape. The phenotype determines how equipped an organism is for its environment, and it is where selection acts. That selection is ultimately registered in the genotype—the genes that allow a trait to be passed to offspring—but the connection between phenotype and genotype retains many mysteries. Arguably it is the biggest mystery of the post-genomic era we are now entering, in which it is proving unexpectedly hard to identify where many inherited phenotypic traits are encoded in the genotype.

In the 1990s Schuster and his colleagues devised a computer program that could predict the simplest features of an RNA's shape (its secondary structure, which is how parts of the chain stick to other parts by pairing-up of bases) from its sequence. For an RNA of 100 bases, there are around $10^{23}$ possible shapes of this sort. But what was remarkable was the way these shapes and their sequences were related.

Naively, you might expect RNAs with a similar shape, and thus presumably phenotype, to share a similar sequence, so that a map of the possible sequences—the sequence space, which can be represented as a many-dimensional space where each grid point corresponds to a particular sequence—is divided up into various "shape kingdoms" (See Not a Patch, a). But that wasn't what Schuster found. Instead, RNAs with the same shape could vary very widely in sequence: You could get the same shape, and therefore potentially the same kind of catalytic function, from very different sequences. But these phenotypic siblings weren't totally isolated from one another in distant parts of the sequence space. Instead, RNAs with the same kind of shape were connected in a network that weaved its way throughout pretty much the whole of sequence space. You could go from one sequence to another with the same shape (and thus much the same function) via a succession of small changes to the sequence, as if proceeding through a rail network station by station. Such changes are called neutral mutations, because they are neither adaptively beneficial nor detrimental. (In fact even if mutations are not strictly neutral but slightly decrease fitness, as many do, they can persist for a long time in a population as if they were quasi-neutral.)

And this was the case for all the $10^{23}$ possible shapes. In other words, this RNA sequence space is threaded with that number of interwoven networks, all interlocking but rarely intersecting. This means that if we consider any given sequence at a particular point in the high-dimensional space, it has a huge number of neighboring sequences that have completely different shapes—and yet it can still mutate step by step into a very different sequence with a similar function, provided that it stays on the right track (See Not a Patch, b).

This tells us two crucial things about the RNA sequence space. First, there are many, many possible sequences that will all serve the same function. If evolution is "searching" for that function by natural selection, it has an awful lot of viable solutions to choose from. Second, the space, while unthinkably vast and multi-dimensional, is navigable: You can change the genotype neutrally, without losing the all-important




**NOT A PATCH** The shape of RNA sequence space is not divided into phenotypic patches, where each color represents a different shape or phenotype (a), but is permeated by phenotypic networks that extend and interweave throughout almost the whole space (b). Each network can be traversed by a series of individual neutral mutations to the sequence.

phenotype. So this is why the RNAs are evolvable at all: not because evolution has the time to sift through the impossibly large number of variations to find the ones that work, but because there are so many that do work, and they're connected to one another.

Susanna Manrubia of the Spanish National Center for Biotechnology has conducted more sophisticated computational studies of how RNA sequence dictates secondary structure, which support this view that there is a lot of redundancy in the genotype-phenotype map.[1] She thinks this feature of RNA might have been crucial for its proposed role in the origin of life. "The existence of multiple genotypic solutions, together with a tolerance to exact molecular structures to perform chemical functions, might have been essential in the emergence of an RNA world," she says.

Proteins have this property too. Different organisms often possess proteins with the same shape and enzymatic function (phenotype), yet typically these will share no more than 20 percent of their amino acids in common. Using a simple model of protein structures, David Lipman and W. John Wilbur of the National Institutes of Health in Maryland showed in 1991 why this should be so: Their simplified model proteins were linked into extended networks in sequence space that can be traversed by neutral mutations one step at a time. In 2001 this apparent redundancy between protein sequence and phenotype was demonstrated experimentally by Anthony Keefe and Jack Szostak at Harvard University. They set out to look for proteins made from randomly assembled amino acids that could bind to the small molecule called ATP, which is the key energy-storage molecule of living cells. Just about any protein that does useful work, such as transporting other molecules or catalyzing their transformation into new forms, uses ATP as the energy source. ATP-binders are therefore vital components of cells. Szostak and Keefe used a chemical method to assemble 80-amino-acid proteins at random from their component parts, and were able to sift through all the variants that they made to find ones that happened to be aptly shaped to bind ATP.[2] They couldn't make anything like the total number of possible permutations of this number of amino acids. But among the tiny fraction (6 trillion) that they did produce, they found four ATP binders. That doesn't sound like a lot, but if there are already four solutions in this incredibly small sampling of the sequence space, there must be an immense number in the rest of the space—about $10^{93}$ of them, the researchers estimated.

Wagner and his coworkers have discovered that this "evolvable" (they call it a robust) structure is a common feature of biological complexity. In 2006 he and his postdoc João Rodrigues began to explore the versatility of the metabolic network of the bacterium *Escherichia coli* (*E. coli*).[3] This is perhaps the most studied of all bacteria, and the biochemical pathways of its metabolism are well mapped out. *E. coli* consumes glucose and makes from it all 60 or so of the key molecular building blocks it needs to survive. But what if just one of those metabolic reactions were altered? Could these "neighbors" of *E. coli* still survive on glucose alone? There is a huge number of such neighbors, but Wagner and Rodrigues calculated the metabolic reactions for more than 1,000 of them, and found that several hundred will also make do with glucose alone. In other words, *E. coli*'s metabolic network is not finely tuned to run on glucose—lots of other variants will work too. The researchers continued to search through the metabolic space, asking whether neighbors of neighbors would also run on glucose. They found that they could just keep on walking through this network of viable glucose-metabolizers until they reached hypothetical organisms that shared only 20 percent of the reactions with *E. coli*. Again, the options are extremely numerous, and all reachable by small neutral steps through the space of possibilities. Evolution sends vast numbers of organisms off to explore

Exactly which genes you have may not matter so much (within reason), because the job they do is more a property of the network in which they are embedded.

this intricately ordered library, seeking good answers to life's problems. As they stumbled upon this unexpected topology of "metabolic space," says Wagner, "I was close to ecstatic."

And gene circuits? Same story. Wagner has collaborated with physicist Olivier Martin to explore the space of hypothetical gene regulatory networks. They searched for different networks that, by mutually regulating the activity of the constituent genes, would produce the same overall patterns of gene expression—that is, the same phenotype.[4] To take a trivial example, in a network of three genes A, B, and C, the same result of switching off expression of gene B could be achieved by either A or C inhibiting B. Even for just a dozen or so genes the number of possible networks of interactions becomes too vast for an exhaustive search, and so the researchers could examine only a tiny region of the space. But the outcome was clear: On the one hand, circuits typically have dozens to hundreds of neighbors with the same phenotype, while on the other hand circuits that differed in more than 90 percent of their "wires" could still produce the same expression pattern.

This helps to explain a puzzling aspect of gene circuits: their robustness. In the late 1990s a team of researchers at Stanford University created around 6,000 mutants of brewer's yeast, each of them lacking a different single gene, and found that many of them thrived just as well as the unmutated yeast did.[5] The same proves to be true for many other organisms: You can obliterate many of their individual genes to no obvious effect. But this is no surprise if there are plenty of similar gene circuits that do much the same job as the original one. Looked at this way, robustness is complementary to innovation: Any network that can evolve new features and forms among a vast array of alternatives must necessarily be robust against small changes, because it almost certainly has an alternative on hand that performs equally well. This realization offers an antidote to an excessively deterministic view of genes: Exactly which genes you have may not matter so much (within reason), because the job they do is more a property of the network in which they are embedded.

Wagner's work is "really innovative—no pun intended—and important stuff," says Johannes Jaeger of the Center for Genomic Regulation in Barcelona, Spain. He is trying to test these ideas by studying the evolution and developmental biology of gene networks that control the growth of insects such as fruit flies. "So far, our results agree with Andreas' insights," Jaeger says. They have found that manipulating this network to switch between sequential and simultaneous formation of the segments of a fly's body is much easier to achieve than expected—it just needs a few tweaks of the regulatory mechanisms, not a wholesale reorganization of genes. "This explains much of the differences in expression patterns in different fly species," says Jaeger. "All kinds of patterns can be produced by the same set of genes."

## Is evolution a law of nature?

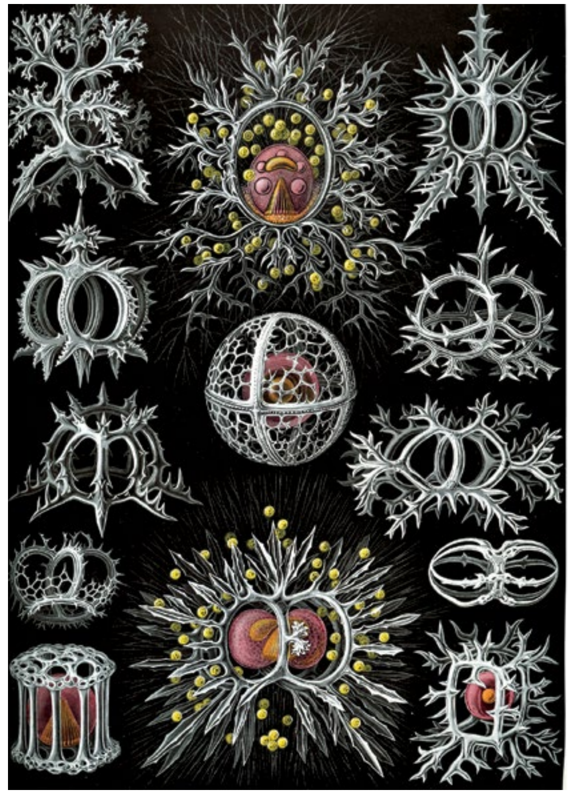
These findings uncover a property of biological systems even deeper than the evolutionary processes that shape them. They reveal the landscape on which that shaping took place, and they show that it was only possible at all because the landscape has a very specific topology, in which functionally similar combinations of the component parts—genes, metabolites, protein or nucleic-acid sequences—are connected into vast webs that stretch throughout the whole of the multidimensional space, each intricately woven amidst countless others.

One might argue that the original creative act of the living world was the generation of the components themselves: the chemical ingredients, such as amino acids and sugars, that comprise the molecules of life. But this now seems like the easy part, the kind of happy accident that chemistry can supply given the right raw materials and environment. The harder question is how one can get beyond that passive soup to kick-start Darwinian evolution. Manrubia thinks that this primal creative step might itself be a consequence of the richness and intimate interweaving of neutral (or quasi-neutral) networks. This means that, even for random, abiotically generated RNA sequences, there is a significant chance of finding ones that perform some useful function. "In a sense, you have function for free if the phenotypes are sufficiently represented in sequence space," she says. And her computer simulations show that such RNA sequences aren't rare. "So sufficiently good solutions to act as seeds of the evolutionary process might arise in the absence of the evolutionary process itself." In particular, there's a fair chance of hitting on sequences that can replicate—and then you're up and running. "Natural selection can very quickly turn mediocre solutions into fully adaptive ones," Manrubia says.

The structure of these combinatorial landscapes of biomolecules then enables nature to make bold and creative innovations rather than being forever consigned to making incremental variations on what already exists. Evolution need only take a random walk along a web of neutral (or at least almost neutral) mutations, that, without impairing the fitness of an organism, surrounds it with very different neighbors: innovative solutions to selective pressures that are there for the taking when the circumstances compel it. Through this neutral drift, organisms can reach locations in phase space which would not have been accessible by strictly adaptive mutation from their original starting position.

The role of such random drift in evolution has been long recognized, and recently evolutionary biologist John Tyler Bonner has argued that it may be more important than previously thought, especially for small organisms whose wide variety of shapes and structures—think of the microscopic marine organisms such as diatoms and radiolarians—do not necessarily reflect any adaptive fine-tuning.[6] The apparent creativity and artistry of such forms has astonished biologists and inspired artists. Now it seems we can understand where this diversity and inventiveness comes from.

What is more, the new perspective offered by the work of Wagner and others might resolve long-standing



**NATURE'S CREATIVITY** Some radiolarians as drawn by the German biologist Ernst Haeckel at the end of the 19th century, showing the dazzling profusion of their variety.

ERNST HAECKEL

disputes about the apparent conflict between the fitness of populations and individuals. Some bacteria seem to undergo more mutations than is "wise" for the individual, if most mutations decrease fitness. An overly simplistic explanation is that many mutations are nonetheless good for the population as a whole because they offer more options for adapting to new environmental challenges. But mutations on robust networks have more chance of being neutral—a feature that is good both for the individual (because it has less chance of incurring deleterious mutations) and for the population (because it provides new ways to adapt when the need arises).[7]

Yet the question that remains is: *Why* does the space of evolutionary options have this essential, robust structure? "We simply don't know why genotype networks are interwoven the way they are," admits Wagner. Jesse Bloom of the Fred Hutchinson Cancer Research Center in Seattle, a specialist on protein evolution, suggests that perhaps that question is back to front: "One could posit that evolution is only able to work effectively if this property exists, and so the things that ended up evolving have this property," he says. But he admits that this would be hard to prove.

However, it seems likely that the answer lies beyond biology. Karthik Raman, a former postdoc in Wagner's lab, now at the Indian Institute of Technology Madras, has studied much the same issues of functional equivalence of different circuits not for genes but for electronic components that carry out binary logic functions. By randomly rewiring circuits of 16 components and figuring out which of them will perform particular logic operations, Raman found that they too have this evolvable topology.[8] But crucially, this property appeared only if the circuits were *complex* enough—if they had too few components, small changes destroyed their function. "The more complex they are, the more rewiring they tolerate," says Wagner. Not only does this open up possibilities for electronic circuit design using Darwinian principles, but it suggests that evolvability, and the corollary of creativity or innovability, is a fundamental feature of complex networks like those found in biology.

Manrubia agrees that complexity is the key. "It seems clear that efficient navigability can only be achieved in genotype spaces of high dimensionality," she says. That simply puts more options in reach—because you have more directions to reach in. "As the number of possible neighbors of a sequence increases, the likelihood that some of those neighbors has a viability comparable to the original one grows." One consequence, she says, is that there could be an adaptive imperative favoring larger genomes, at least for organisms inhabiting varying environments: That way, you gain more in robustness than you lose in the labor of replicating and maintaining a lot of DNA.

These ideas suggest that evolvability and openness to innovation are features not just of life but of *information itself*. That is a view long championed by Schuster's sometime collaborator, Nobel laureate chemist Manfred Eigen, who insists that Darwinian evolution is not merely the organizing principle of biology but a "law of physics," an inevitable result of how information is organized in complex systems. And if that's right, it would seem that the appearance of life was not a fantastic fluke but almost a mathematical inevitability.

**PHILIP BALL** is the author of *Invisible: The Dangerous Allure of the Unseen* and many books on science and art.

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# To Be More Creative, Cheer Up

*The way to tap your inner Hemingway is not how you think*

**BY KIRSTEN WEIR**

I **POUR A CUP OF COFFEE**, sharpen my pencil, and get ready to create. I've dusted off a half-conceived novel outline I abandoned three years ago, but this time I'm not waiting for my muse to intervene. Instead I hit the play button on the Creative Thinker's Toolkit, an audio lecture series from The Great Courses that I've downloaded on my computer.

Gerard Puccio, a psychologist who heads the International Center for Studies in Creativity at SUNY Buffalo State, and the voice of the toolkit, tells me to engage in "forced relationships." Choose a random object, he instructs. I scan my office and settle on a bag of Skittles left over from Halloween. Next, he says, describe the object's attributes. "Sweet, round, colorful, chewy," I write. I start to draw more fruitful connections. The word "small" leads me to think about making the main character isolated, reacting against a life that has become too constrained.

I'm intrigued. Is creativity a skill I can beef up like a weak muscle? Absolutely, says Mark Runco, a cognitive psychologist who studies creativity at the University of Georgia, Athens. "Everybody has creative potential, and most of us have quite a bit of room for growth," he says. "That doesn't mean anybody can be Picasso or Einstein, but it does mean we can all learn to be more creative."

After all, creativity may be the key to *Homo sapiens*' success. As a society, we dreamed up stone tools, the combustion engine, and all the things in the SkyMall catalog. "Our species is not fast. We're not terribly strong. We can't camouflage ourselves," Puccio told me when we spoke on the phone. "What we do have is the ability to imagine and create new possibilities."

Creativity is certainly a buzzword these days. Amazon lists more than 6,000 self-help titles devoted to the subject. A handful of universities now offer master's degrees in creativity, and a growing number of schools offer an undergraduate minor in creative thinking.

"We've moved beyond the industrial economy and the knowledge economy. We're now in the innovation

ILLUSTRATIONS BY CHRISTINA GRANSOW

economy," Puccio says. "Creativity is a necessary skill to be successful in the work world. It's not a luxury anymore to be creative. It's an absolute necessity."

But can you really teach yourself to be creative? A study published in the *Creativity Research Journal* in 2004 reviewed 70 studies and concluded that creativity training is effective. But it wasn't entirely clear how it worked, or which tactics were most effective. More recent studies, however, take us inside the brain to tap the source of our creative juices, and in the process upend longstanding myths about what it takes to be Hemingway or Picasso.

**SOME OF THE EARLIEST** scientific studies of creativity focused on personality. And some evidence suggests that innovation comes easier to people with certain personality types. A 1998 review of dozens of creativity studies found that overall, creative people tend to be more driven, impulsive, and self-confident. They also tend to be less conventional and conscientious.

Above all, though, two personality traits tend to show up again and again among innovative thinkers. Unsurprisingly, openness to new ideas is one. The other? Disagreeableness.

"Highly creative people tend to run counter to the popular ways of doing things. They tilt at windmills and go against the grain," says Rex Jung, a neuropsychologist who studies creativity at the University of New Mexico. "Think of Steve Jobs—a prickly personality to say the least."

I try to be likable. I'm also a rule follower who thoroughly enjoys spending quality time in my comfort zone—three strikes against my creative capacity. Yet fortunately for me and my conformist counterparts researchers have come around to thinking about creativity not as a personality type, but as a cognitive process.

"Creativity can be thought of as a particular kind of problem solving," Puccio says. "It's a way of thinking that's applied to open-ended problems where there isn't an off-the-shelf answer." If creativity is a cognitive process, we should be able to learn to do it better.

For decades, creativity researchers have generally thought of the process in terms of four basic steps. Step one is preparation. Painters need to understand something about color and form; composers have to know

Too much analysis is like trying to drive a car with a parachute hanging off the back. It just puts a drag on your thinking.

how to read music. Sorry, no shortcuts. After preparation comes incubation. During this step, ideas meander through your brain's neural networks, bumping into other ideas to combine in interesting ways. When the right ideas collide, you experience step three: illumination. This is the light bulb coming on, the fabled Aha! moment. The fourth and final step is verification. This is creativity's logical bit—the critical thinking component in which you figure out if the idea has legs.

Each step is distinct, and requires a complex set of cognitive abilities. In fact, creativity draws on so many different skills that it can be hard for researchers to know where to start. "As we home in on the different cognitive systems that are involved in different aspects of creativity, it pulls in more and more systems until eventually the whole brain is involved," Jung says.

That in itself is an intriguing finding. For one thing, it contradicts the popular (but erroneous) belief that creativity is a right-brained endeavor, while the left side is supposedly in charge of analytical thinking and rule-based processes like language. "Certainly you'll see regions in the right hemisphere that are associated with creativity, but just as often, if not more often, you'll see regions in the left," says Jung.

So far, much of the scientific research of creativity seems to have focused on the idea-floating incubation stage of the process. Research from Jung's lab and others suggests that incubation relies strongly on a neural pathway known as the default mode network (DMN). This neural network, which roughly spans the inner portion of the brain, is most active when we're not concentrating our attention on a task.

During these idle moments the DMN gets to work, scanning our surroundings for the details of the environment. But the DMN doesn't just turn our attention outward. It's also the part of the brain involved in self-reflection. "That's the part of your brain that you use when you're thinking about yourself, your relationships, how you'd handle a certain situation," Jung says. "It's daydreaming."

But creativity is more than just staring at the clouds. During creative thinking, there's a push-and-pull between the default mode network and another pathway called the cognitive control network (CCN). This is the network most active during so-called executive functions such as planning, reasoning, and problem solving. If the DMN makes up the inner portions of the brain, the CCN is more like its "outer rind," Jung explains.

Our mental processes rely on vast networks of interconnected brain areas. In the DMN, two important network hubs appear to be the medial temporal lobe, which provides you with information from memories and prior associations, and the medial prefrontal cortex, which allows you to put that information together in mental simulations. In the CCN, the prefrontal cortex—long thought to be a locus for planning and decision making—unsurprisingly plays a starring role.

The DMN and CCN aren't exactly in opposition with one another, however. "Like a Venn diagram, there's an intersection between them, a back-and-forth," Jung says. "It's a dance between internal and external cognitive networks as you bring a new idea into being."

The first step in that dance is often a process called divergent thinking—the hallmark of incubation. Think of it as tuning out, or letting your consciousness go fuzzy. Distancing yourself from a creative challenge allows your thoughts to travel down new neural pathways, allowing for new connections and fresh ideas, Puccio says. "You're casting a very wide net to find an insight or a way forward."

Multiple studies have found that divergent thinking is a strong predictor of one's creative achievement—better even than IQ. And happily for researchers, divergent thinking can be assessed fairly easily using behavioral measures in the lab, making it a useful metric of creative potential. (A common test of divergent thinking: In two minutes, list all the uses you can think of for a common household object, like a toothpick, then determine how many are original or surprising.)

For someone looking for a creativity boost, divergent thinking is the place to start. The trick, says Puccio, is learning to deliberately manage your own thinking. "All humans are able to engage in both divergent and convergent [or analytical] thinking, but we often don't do that in a very efficient way," he says.

For a prime example of mental efficiency, consider Ernest Hemingway. "When he got up in the morning he would do free writing with a pencil, capturing all of his thoughts. He wouldn't use punctuation. There would be half thoughts," Puccio says. "Once he had enough material, then he would shift to his typewriter and start to synthesize."

In one clever study of creativity, Charles Limb, a physician at Johns Hopkins University, scanned the brains of jazz musicians as they noodled on tiny keyboards specially designed to be played inside a cramped fMRI machine. When the musicians improvised (versus practicing scales or playing a memorized composition), a spot in the medial prefrontal cortex perked up. That region has been linked to the creation of autobiographical narrative, suggesting that improvising might literally be a way of telling one's story through musical notes. Meanwhile, the lateral areas of the prefrontal cortex—areas often associated with self-monitoring and evaluation—were deactivated during improvisation. Freed from self-judgment, they could let their creativity flow.

I've already identified one of my big problems: I edit as I go. By the time I get to the second paragraph of an article, I've written and rewritten that first paragraph until it shines. I judge and discard new ideas without ever adding them to the list. Mixing convergent and divergent thinking "is like trying to drive a car with a parachute hanging off the back," Puccio says. "It just puts a drag on your thinking."

To give my divergent thinking skills a workout, I turn back to his lectures. I vow to channel Hemingway and list every idea that floats across my consciousness, without judgment.

For my next exercise, I pull up four random photos from Flickr. I take time considering each image, one by one, before turning back to my own creative challenge. A shot of a dapper young man in a trim suit and expensive wristwatch, for example, leads me to consider the importance of outward appearances and the significance of material objects in my characters' lives.

I'm starting to see some payoffs, though it still feels a little forced. Luckily, there are almost endless ways to practice divergent thinking, Jung tells me. There's often some trial-and-error involved as people figure out what works for them. Some people meditate. Others listen to music or take bubble baths or, yes, turn to drugs and alcohol.

"Most creative people have figured out a way to do the incubation thing—whether it's meditation or staring out the window or taking long walks so their ideas can percolate," Jung says. "It's finding that magic space where you're not actively engaged with the external world, and not just surfing the Internet."

In a 2009 review of more than three dozen studies of incubation, researchers from Lancaster University found that setting aside a problem was helpful for improving performance on divergent thinking tasks. Yet some methods may be better than others, they discovered. The trick appears to be engaging your mind, but just a little bit. The researchers found tasks that required a low mental investment, like reading, were most beneficial to the problem-solving process. Mentally demanding tasks like counting backward were less helpful—and surprisingly, plain old rest was also less effective at boosting divergent thinking.

Of course, there's more to creativity than divergent thinking. The first and fourth steps of the creative process—preparation and verification—are fairly straightforward. But many would argue that the third step—illumination—is where the magic happens. And scientists are just starting to consider the Aha! moment from a neurological point of view.

Mark Beeman, a cognitive neuroscientist at Northwestern University, focuses on the science of insight, often in collaboration with John Kounios, a cognitive scientist at Drexel University. They've found distinctly different patterns of brain activity when people solved problems using insight versus problems solved analytically. Interestingly, those patterns appeared milliseconds before the problem was ever presented. In other words, some brains appeared to be primed for insight.

The obvious question, then: How do you prepare your mind for a stroke of genius? One important element, Beeman says, is to maintain a loose state of attention rather than focus intently on a problem. This goes hand in hand with divergent thinking. "Incubation and insight are highly related," he says. "You've been working on a problem, you set it aside and boom! It comes to you."

Some people have naturally leaky attention filters, he adds. But the concentrators among us can take steps to maximize the potential for insight. For one thing, it helps to have a sunny outlook. Beeman and his colleagues found that people are more likely to maintain broader attention and solve problems when they're in a positive mood.

It helps to have a sunny outlook. People are more likely to solve problems when they're in a positive mood.

"The basic idea is that a positive mood loosens the grip of attention, so that stimuli and ideas that used to get filtered out can now have a greater impact on [mental] processing," he says. "Stress and anxiety have the opposite effect, narrowing attention, which can be good for focused analytic thinking—as long as you keep focus on the right information—but bad for broader creative thinking."

Beeman's team has also found evidence that you can actively change your attention state. He flashed images (of sheep, for example) in front of volunteers, too quickly for them to consciously recognize what they'd seen. But with practice, they began to trust their intuitions and somehow tap into the weak associations—wool? farm?—that bubbled up in the moments after the picture flashed before their eyes. They got better at identifying the images, and as they did, they solved more problems with insight. Subliminal messages obviously aren't easy to replicate at home. But stay tuned. "I'm pretty convinced that what we're studying in the lab is relevant for real-world creativity," he says.

**MEANWHILE, WE CAN TAKE CUES** from more fundamental findings from the world of creativity research. Robert Bilder, director of the Tennenbaum Center for the Biology of Creativity at the University of California, Los Angeles, is trying to work out creativity's basic biochemistry. He's focusing on three broad cognitive abilities he believes are crucial to creative achievement: the ability to generate novel ideas; response inhibition, or the ability to shake off old habits and break out of a routine; and working memory, the skill that allows people to hold disconnected ideas in the conscious mind long enough to use them.

All three are complex abilities that can't easily be pinpointed to specific regions of the brain, Bilder says. Instead, he's exploring the thickets of brain networks that allow us to engage in these processes, and the genes that code for them. He's also studying molecular expression to figure out how and when the responsible genes are switched on and off. To do that, he's looking to our creative counterparts in the animal kingdom.

Zebra finch females, for instance, prefer mates whose songs stand out. So zebra finch males innovate, producing novel melodies to woo the ladies. Researchers have identified gene networks that enable song production during finch development. One such genetic pathway involves the gene *FOXP2*—a gene long known to be important for speech and language production in humans.

Elsewhere, scientists working with mice have started to identify the gene networks responsible for changing learned habits, and others that seem to give some rodents superior working memories. Bilder is now studying those genes to see what role they play in our own creative thinking. It's an ambitious project. "The genetic underpinnings are so complex, we can estimate there may be upward of 10,000 genes involved in a particular trait," he says.

Despite the challenge, Bilder says we can already begin to draw some practical conclusions from these efforts. Consider the finding that inhibition is necessary for creativity. "Many people think being uninhibited is the most important thing," he says. But it's critical to inhibit habits that prevent us from realizing our creative potential—like my tendency to shoot down ideas before they're fully formed.

Working memory is also an obvious target for self-improvement. Some research suggests that working memory is a skill that can be improved with systematic training. But we'd also do well to recognize our limits. "Many people probably attempt to keep things in working memory when it's not realistic to do so," Bilder says. "People beat themselves up trying to do things that aren't neurophysiologically possible." Luckily, there are workarounds. Tools such as mind maps—diagrams to visually organize information—can serve as a kind of "working memory prosthesis," he says.

Bilder offers up one last bit of practical advice: Just get your ideas out there—on paper, on canvas, out of your head. "If you get that thought or product out there and externalize it, it frees you up to go onto the next idea," he says. In fact, creative output is one of the best predictors of creative success. For all the one-hit-wonders, there are many more examples of creators who generated a huge body of work. "Picasso created somewhere between 10,000 and 50,000 works during his life," Bilder says. "Don't worry about whether [your idea] is good enough. Once it's out there, then you can say, 'oh that was terrible'—and keep going."

Puccio's Creative Thinker's Toolkit offers similar advice. Hemingway may have been famous for his brevity, but he wrote 47 different endings to *A Farewell to Arms*. Come up with enough ideas, and a good one is sure to stick.

Creativity, in other words, is a slog. So I'll keep practicing. I can't promise you'll ever see my Skittles-inspired novel on bookshelves. But I'm excited to take a more hands-on approach to boosting my creative capacity. I can keep waiting around for the Aha! moment. Or I can get to work.

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**KIRSTEN WEIR** is a freelance science writer in Minneapolis.

"HOW THE OBITS BECAME MY MUSE"
ILLUSTRATION BY **DANIEL GREENFELD**

# Robots Can't Dance

*Why the singularity is greatly exaggerated*

**BY JEANNE CARSTENSEN**

**CAN A ROBOT BE CREATIVE?** Advances in cloud robotics—machines connected to supercomputers in the cloud—have given self-driving cars, surgical robots, and other "smart" devices tremendous powers of computation. But can a robot, even one supercharged with artificial intelligence, be creative? Will a mechanical Picasso paint among us?

Ken Goldberg is the ideal person to ask. For one thing, when he was getting his Ph.D. in computer science at Carnegie Mellon University, Goldberg built a robot that painted. For another, Goldberg, 53, is a computer engineer, roboticist, and artist himself. He grew up in Bethlehem, Pennsylvania, where he forged his creative path. "I was an outsider, at odds with what other kids were doing, and became very interested in art," he says.

Today Goldberg is Professor of Industrial Engineering and Operations at the University of California, Berkeley, where he also directs a lab on automation sciences, a center for medical robots, an initiative on data and democracy, and a center for new media. He's published more than 150 peer-reviewed papers on topics such as automation algorithms, and his artwork has been exhibited at the Pompidou Center, Whitney Biennial, and Berkeley Art Museum.

Goldberg has strong views on creativity and how it differs in computers and people. His energy and intellect are infectious as his mind races from one idea to another. Our conversation ranged over his own projects and heroes, from gothic literature to Google Glass, Freud to philosopher Hubert Dreyfus. We spoke at his UC Berkeley lab and at a restaurant in Mill Valley, California, near his home, where he lives with his wife, Tiffany Shlain, a filmmaker and the founder of the Webby Awards, and their two daughters, Odessa and Blooma.

***What's been your most creative moment in science?***

I spent a summer in graduate school trying to find the

ILLUSTRATION BY JAMES YANG

mathematical proof of completeness for an algorithm I had written to orient polygonal objects. I lived alone and every day I would write out ideas. To keep my sanity I made paintings of the rickety old stone stairs in the alley outside of my apartment. I woke up one morning and realized I could prove it using a step function. It was a true Aha! moment. The proof has been cited over 400 times.

***Einstein talked about how the greatest scientists are also artists. For him all great achievements in science must start from intuitive knowledge.***

Agreed. Intuition is a hunch, sensing there's an opportunity—how to set up the problem. As an artist it's finding the right idea or concept. Making an opera about Klinghoffer, for example—that's not an obvious subject for composer John Adams to have come up with. In both science and art, one must rely on a gut feeling about which direction to go.

***Tell us about your painting robot.***

I liked the idea of a robot being able to demonstrate that a machine can go through the motions of painting but can't capture the eloquence, the subtlety, the nuance of a human painter. What also fascinated me was how people responded to the robot. The performative aspect of a moving robot was very hypnotic and fascinating to them.

**UNCANNY BALLERINA** Ken Goldberg with a 1911 music-box ballerina, an early automaton that tapped into cultural anxiety about an increasingly mechanistic world.

***Sounds like that laid the groundwork for your "Telegarden." Tell us about that.***

In 1993 I was teaching at USC. My students came to me and showed me this amazing thing called the World Wide Web. We sat around brainstorming about what we could contribute. Since we were working in robotics and had robots in the lab we thought, "Why don't we connect a robot to this Web and let people control it from anywhere in the world?" We got super excited about the idea of having a robot do something that was ironic. We wanted to have it tend a garden. A garden is interesting because in some way it's the last thing you expect a robot to be doing. I loved the juxtaposition of the natural and the digital worlds.

The installation had a planter with 18 inches of soil and an industrial robot arm in the center with a Web interface. Over 100,000 people visited. They could visit the garden from a Web page and participate by helping to water it, and then if they watered for a certain amount of time, they would get their first seed to plant. Interesting social dynamics emerged. People would ask others to watch their plants when they were away, which created a sense of community. Yet at the same time there was something incongruous about people sitting at their computers planting seeds.

***And this led you to coin the term "telepistemology."***

Right. One afternoon I got an email out of the blue

**THE TELEGARDEN** Goldberg and company allowed Web users to view and interact with a remote garden filled with living plants. Members could plant, water, and monitor the progress of seedlings via the movements of an industrial robot arm.

ALL PHOTOS COURTESY OF KEN GOLDBERG

from a student in Texas who asked how he could be sure the garden was real. I was surprised because it seemed obvious. Then I realized it was a very deep question because many hoaxes had been done on the web, and it's not too hard to imagine the whole thing could have been faked. We wondered, how would we prove that it was real?

Around that time I came to Berkeley and met with the philosopher Hubert Dreyfus, who is one of my heroes. He told me this is a very old question at the heart of epistemology: What is knowledge? What do we know? How do we know it? We would meet every two weeks to wrestle with this question and we realized it was interesting because technology had always had an influence on epistemology. When Galileo developed a telescope, and when the microscope was developed—this caused a radical shift in thinking that led Descartes to the sense of doubt that was the basis for the scientific method.

***What were Dreyfus's views on AI and creativity?***

He's always been a critic of artificial intelligence at any level. He was vocal about this in the 1960s when everybody was predicting that computer systems were going to be intelligent within the decade. He was one of the lone dissenters. He wasn't a computer scientist but a philosopher saying, "No, you're missing that a fundamental aspect of intelligence is experience and that requires embodiment." He knew that to understand the world you needed to be inside the world, you needed to experience its behaviors and responses to you. Well, he was right. We may be making progress in being able to do things like recognize a cat in a photograph. But there's a huge gulf between that and doing something creative.

***In 1968, Marvin Minsky said, "Within a generation we will have intelligent computers like HAL in the film, 2001." What made him and other early AI proponents think machines would think like humans?***

Even before Moore's law there was the idea that computers are going to get faster and their clumsy behavior is going to get a thousand times better. It's what Ray Kurzweil now claims. He says, "OK, we're moving up this curve in terms of the number of neurons, number of processing units, so by this projection we're going to be at super-human levels of intelligence." But that's deceptive. It's a fallacy. Just adding more speed or neurons or processing units doesn't mean you end up with a smarter or more capable system. What you need are new algorithms, new ways of understanding a problem. In the area of creativity, it's not at all clear that a faster computer is going to get you there. You're just going to come up with more bad, bland, boring things. That ability to distinguish, to filter out what's interesting, that's still elusive.

***Today's computers, though, can generate an awful lot of connections in split seconds.***

But generating is fairly easy and testing pretty hard. In Robert Altman's movie, *The Player*, they try to combine two movies to make a better one. You can imagine a computer that just takes all movie titles and tries every combination of pairs, like *Reservoir Dogs* meets *Casablanca*. I could write that program right now on my laptop and just let it run. It would instantly generate all possible combinations of movies and there will be some good ones. But recognizing them, that's the hard part.

***That's the part you need humans for.***

Right. The Tim Robbins movie exec character says, "I listen to stories and decide if they'll make good movies or not." The great majority of combinations won't work, but every once in a while there's one that is both new *and* interesting. In early AI it seemed like the testing was going to be easy. But we haven't been able to figure out the filtering.

***Can't you write a creativity algorithm?***

If you want to do variations on a theme, like Thomas Kinkade, sure. Take our movie machine. Let's say there have been 10,000 movies—that's 10,000 squared, or 100 million combinations of pairs of movies. We can build a classifier that would look at lots of pairs of successful movies and do some kind of inference on it so that it could learn what would be successful again. But it would be looking for patterns that are already existent. It wouldn't be able to find that new thing that was totally out of left field. That's what I think of as creativity—somebody comes up with something really new and clever.

***Can you think of an example?***

One simple and beautiful example is a performance piece by Emma Sulkowicz, an art student at Columbia University, who said she was raped. She carried her mattress around campus for weeks. It was astoundingly elegant and simple and utterly original. Could a robot do that sort of thing? No. But—and this is my sentimental side—I don't want it to happen. I want that to be something that we keep for ourselves as humans.

***You and your wife made a short film about the "uncanny." What is the uncanny?***

It's one manifestation of a broad theory that Freud wrote about in his 1919 essay, "The Uncanny." We have a deeply unsettled reaction to something when it's on the borderline between alive and dead or real and fictional. It goes back to gothic literature and questions about the line between man and machine. It arises out of the study of the automaton and thinking of the human body as a mechanism. That motivated automata makers to make systems that looked increasingly human-like and try to blur that line. It led to anxiety about what is real, what is human? What is alive versus what isn't? You have a whole literature built around vampires and zombies and Frankenstein. It's really at the root of all horror stories and it's very operative in the realm of robotics. If you make a robot that's too much like a human it becomes profoundly repulsive. So if you're trying to create something you would want in your home, you don't want it to look too human-like. This wonderful cultural phenomena is still very relevant today, where we can actively trigger the uncanny and it's a very visceral real response.

***How is it triggered today?***

By something like Botox. When someone has too much Botox, there's a creepiness to them. They've shifted their humanness a little too far and you start to feel anxiety. Google Glass triggers this. It creates this anxiety and ambiguity about whether the person wearing it is completely human or half-android. It also triggers the fear of surveillance. So you might say that Google Glass is the uncanny "double whammy." It's about simulacra and surveillance. It combines two aspects that people really don't seem comfortable with.

***Have you ever taken the Turing Test?***

One reason why I got involved with robotics and AI was that when I was about 9, my cousins sat me down at a computer at the Lawrence Berkeley Lab and said, go ahead, talk to it. It was ELIZA, which I now know has about one page of code. I didn't think it was human but I was intrigued by it. Part of its genius, the way it

**POWER AND WATER** Goldberg, in collaboration with Margaret Lazzari, designed a robotic painting machine and 12 large-scale paintings, executed by hand and by the robot. The images were based on events surrounding the building of the Los Angeles Aqueduct between 1906 and 1913.

maintained the illusion of an intelligent conversation, was that it kept throwing back questions. "Why do you think so?" "Can you tell me more?" But as a friend of mine said, it's not so much the computer passing the Turing Test as the human failing it. We do that all the time. We think that we're talking to something but it's actually that we're not paying attention.

***Could you imagine having a robot companion?***

I never did until I saw *Robot & Frank* with Frank Langella. The Frank character was so real I found myself identifying with him. I imagined myself in his position: home alone and needing help or company—with a robot showing me stuff, telling me jokes. It's not inconceivable that a robot could generate topics by mining my email and photographs and travelogues and suggesting a discussion about treehouses because it found a childhood photo of one and bookmarked articles on the topic.

***You know how kids need to be educated about social media? Will we also need robot education? If it moves like a human and talks like a human, won't people get confused?***

That's interesting. But we actually have a good inherent test about this. When my girls play with Siri they have fun but they know it's not a real being.

***This is a dark scenario. But what if a child were raised in an orphanage by robot nannies?***

Right, it's one thing to have a robot caretaker for an old codger like me, but when you turn that around and say the robot is taking care of my 3-year-old, it seems like there is something really wrong. But we park our kids in front of the TV to watch *Sesame Street*. We all do this. If you had something that could interact with them, to teach them a language or something like that, it could be interesting.

***Do sophisticated robots challenge humans to be more aware of qualities that are unique to us?***

If you have a robot caretaker six days a week then you will probably very quickly appreciate the human on the seventh day in a whole new way. I think robots help us appreciate human qualities that robots lack. I don't want to say forever, but for as long as I can imagine there is going to be a sizeable gap.

***What has working with robots taught you about being human?***

It has taught me to have a huge appreciation for the nuances of human behavior and the inconsistencies of humans. There are so many aspects of human unpredictability that we don't have a model for. When you watch a ballet or a dance or see a great athlete and realize the amazing abilities, you start to appreciate those things that are uniquely human. The ability to have an emotional response, to be compelling, to be able to pick up on subtle emotional signals from others, those are all things that we haven't made any progress on with robots.

***What's the most creative thing a robot has done?***

One of my favorites is by the engineer and media artist Raffaello D'Andrea. He worked with a sculptor and they designed a chair that would suddenly collapse. There was a pause and then all the pieces would start to move, find each other, and reassemble into a chair. There's something very elegant about this idea of a chair that's designed to fall apart and come back together on its own. It brings up all these whimsical ideas of magic and yet it's a beautiful and very complex machine.

***Can robots help humans be more creative?***

That happens every day. All the new tools for making movies and making music have been enormously beneficial for creativity. And computers and robots are relieving us of tedious tasks like handling documents and filing. That allows us to spend more of our time being creative. Think of the time you would spend doing research for a book, going to the library, digging up information, walking through the stacks and finding out that the perfect book is gone, somebody else has taken it. Now you have access to all this information at your fingertips. Dozens of times when I thought I had a new idea I would go on the Internet and probe around only to find that somebody else had exactly the same idea and did it. I save myself all the trouble of trying to be creative with some thing that somebody has already done. And that frees me up to spend my creative energy on something else.

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"HOW ISIS BROKE MY QUESTIONNAIRE"
ILLUSTRATION BY **MOLLY MENDOZA**

# Brain Damage Saved His Music

*After a chunk of his brain was removed, guitarist Pat Martino got his groove back*

BY BRIAN GALLAGHER

**FIVE YEARS AGO,** when neurosurgeon Marcelo Galarza saw images from jazz guitarist Pat Martino's cerebral MRI, he was astonished. "I couldn't believe how much of his left temporal lobe had been removed," he said. Martino had brain surgery in 1980 to remove a tangle of malformed veins and arteries. At the time he was one of the most celebrated guitarists in jazz. Yet few people knew that Martino suffered epileptic seizures, crushing headaches, and depression. Locked in psychiatric wards, he withstood debilitating electroshock therapy.

It wasn't until 2007 that Martino had an MRI and not until recently that neuroscientists published their analyses of the images. Galarza's astonishment, like that of medical scientists and music fans, arises from the fact that Martino recovered from surgery with a significant portion of his brain and memory gone, but his guitar skills intact. In a 2014 report in *World Neurosurgery*, Galarza, of the University Hospital in Murcia, Spain, and colleagues from Europe and the United States, wrote, "To our knowledge, this case study represents the first clinical observation of a patient who exhibited complete recovery from a profound amnesia and regained his previous virtuoso status."[1]

Martino is now 70 and has released over 30 albums. He continues to tour around the world and according to many jazz critics and musicians he plays with more felicity and creativity than ever. And in Martino's case that is really saying something. Since he was a teenager, the guitarist has been known for fleet fingers and surprising improvisations. Grammy Award-winning guitarist George Benson told an interviewer that he saw himself as the young phenom around New York City in the 1960s until he saw Martino play one night in Harlem. "I was flabbergasted, man!" Over the years, Benson said, Martino "stayed on my mind because I knew that there was another standard out there that all guitar players had to recognize, and he was setting it. He showed us that there was much more to the guitar than we were hearing."

Martino has also put on a show for neuroscientists. His case demonstrates neuroplasticity, the brain's remarkable ability, during development and learning, to "optimize the functioning of cerebral networks," wrote Hugues Duffau, a professor and neurosurgeon at Hôpital Gui de Chauliac at Montpellier University Medical Center in France, who studied

ILLUSTRATION BY AGATA ENDO NOWICKA

Martino's case. The guitarist's recovery epitomizes the ability of the brain to improvise—to compensate for malformations or injuries by wiring new connections among brain regions that restore motor, intellectual, and emotional functions. For an encore, say neuroscientists, Martino's story is about music and how it helped shape his brain in ways that revived his life.[2]

**MARTINO WAS BORN AND RAISED** in Philadelphia, where he lives today. Although he had hallucinations and seizures since he was 10 years old, he was misdiagnosed by psychiatrists and psychologists for more than two decades. Invariably they told him he suffered from manic depression, bipolar disorder, or schizophrenia. It wasn't until 1980, when he was 35, that Martino learned, following his first computed tomography (CT) scan, that the cause was an arteriovenous malformation, or AVM—an abnormal entanglement of veins and arteries that formed in the part of his brain located just behind his left ear. It looked like "a bundle of worms," said Frederick Simeone, the surgeon who saved Martino's life, in a 2009 documentary, *Martino Unstrung: A Brain Mystery*.[3]

The AVM may have been there from birth, posing an obstacle to the normal development of his left temporal lobe functions—primarily the ability to store and express memories. Even so, Martino could only recall a single instance when a seizure struck while he was performing on stage, in 1976. He was just outside of Marseille, France, at the Riviera Jazz Festival, playing on a mountaintop outdoors with over 200,000 people in attendance. "Right in the midst of a really heavy-duty, burning section, I stopped playing and stood there for about 30 seconds," Martino wrote in his 2011 autobiography *Here and Now!* "During these moments of seizure, it feels like you're falling through a black hole."[4]

Four years later, while he was in Los Angeles teaching at the Guitar Institute of Technology, he had a near-fatal seizure that left him hospitalized. John Mulhern, a good friend of Martino's, who would head the recording department at GIT, was there when the seizure struck and remembered seeing Martino on his bed, "bobbing up and down like a toy." At the Los Angeles hospital, doctors diagnosed the AVM, which they believed had hemorrhaged. Martino was told he had two hours to live. But the native Philadelphian wanted to travel home for the surgery.

The surgery had two phases: first, surgeons removed a blood clot that had formed. Then they gave Martino a cerebral angiography, a procedure in which a dye is introduced into the brain's blood flow so that, using an X-ray, the surgeons could see where they would have to cut. To remove the "bundle of worms," Simeone sliced away 70 percent of Martino's left temporal lobe.

Martino wrote that he felt like a zombie after the operations. He didn't know his name, recognize his parents, or know he was a musician. Martino had severe retrograde amnesia, an inability to recall events and knowledge prior to the seizure that nearly killed him. In a recent interview with *Nautilus*, Martino said the blankness and limbo he experienced after surgery reminded him of a film released that year, *The Lathe of Heaven*. It was adapted from a 1971 dystopian science-fiction novel of the same title by Ursula K. Le Guin, in which a man is horrified to find that his dreams rewrite the past. "It was a terrible place to be," Martino said.

It was also a distressing place for his father, Mickey, a musician himself. Martino said that as a boy he wanted to be a jazz guitarist because he loved his father and thought becoming one would make him proud. It did, and that made it all the more painful for Mickey to see his son forget his love of music. With Martino living back at home in Philadelphia after the surgery, his father, hoping to bring back his lost memories, began to play his son's jazz records in the house. "I would lie in my bed upstairs and hear them seep through the walls and the floor, a reminder of something that I had no idea that I was supposed to be anymore, or that I ever was," Martino wrote.

Upset that Martino kept walking past his guitar without interest, Mickey asked Mulhern to come over and play for him. Mulhern had taken guitar lessons from Martino and often, to Martino's aggravation, had played a major seventh chord when Martino wanted a minor ninth. Now, working through a book of Martino's old guitar exercises, Mulhern struck a major-seventh chord. "Move over!" Martino said. He grabbed his guitar and began playing with his old drive. Over the coming months the pain and misery of his amnesia and post-surgery depression began to lift.

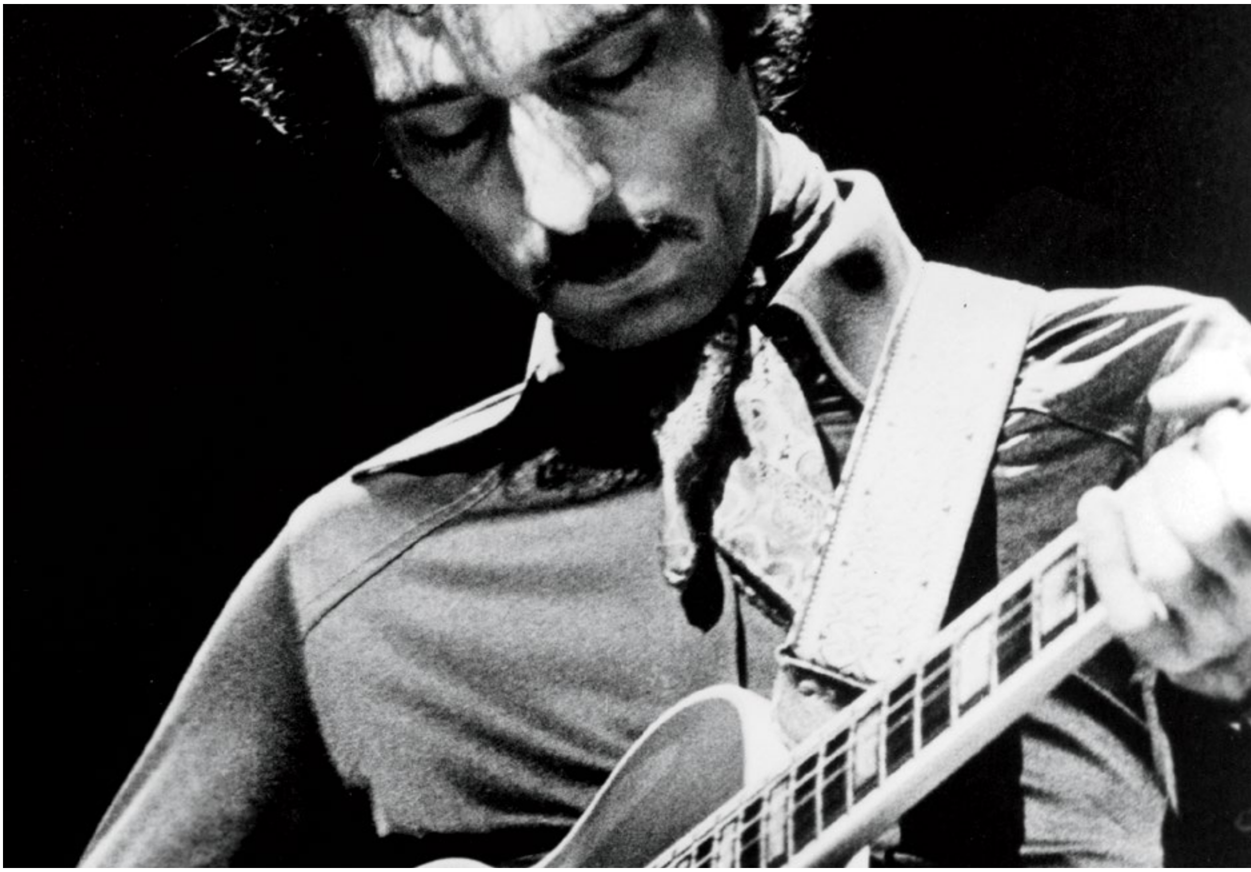
"As I continued to work out things on the instrument, flashes of memory and muscle memory would

MICHAEL OCHS ARCHIVES / STRINGER

gradually come flooding back to me—shapes on the fingerboard, different stairways to different rooms in the house," Martino wrote. "There are secret doorways that only you know about in the house, and you go there because it's a pleasurable thing to do. And that's how you remember how to play; you remember the pleasure of it." Seven years after his surgery, and 10 years after his previous album, spookily titled *Exit*, Martino released *The Return*.

"You don't remember me, do you?" the actor Joe Pesci said to Martino. "I'm going to tell you what you used to drink in 1963."

**MARTINO'S RETURN TO VIRTUOSITY,** say neuroscientists, exposes the rooms and secret doorways of memory in the brain. In the 2014 *World Neurosurgery* report, Galarza noted that after carving out 70 percent of somebody's left temporal lobe, with some underlying damage to the hippocampal region, physicians might expect a patient to have "almost complete memory loss."



The left temporal lobe, Galarza explained, is "directly involved" with verbal auditory memory, talking, and understanding speech. A battery of cognitive tests in 2007 revealed Martino had a hard time relaying the meaning of some abstract and uncommon words and defining more common ones. Shown a picture of a corkscrew, for example, he was only able to muster, "It's used to drill off … a wine bottle." When asked when the Beatles came to America, Martino said sometime between 1961 and 1963 (he was close; it was 1964). But when asked to name a Beatles song, the musician said he couldn't name a single one.

Martino's case underscores three key levels of memory. Semantic memory, which stores impersonal knowledge and facts like names and dates, is associated with the temporal lobes. Martino's lobectomy could explain why he couldn't recall the names of Beatles songs, as it's possible the surgery sliced away the ability to recall semantic memories.

Episodic memory, the kind of autobiographical, experiential memory that William James once compared to a "direct feeling … suffused with a warmth and intimacy," was clearly affected in Martino's case.[5] After all, he couldn't remember he was a musician, recall his family and friends, or relive his experiences with them. That failure might seem puzzling, as episodic memory is associated with the hippocampal and prefrontal cortex regions of the brain, not damaged by his surgery. However, Paul Broks, a British neuropsychologist, cowriter of the documentary *Martino Unstrung*, and a coauthor of the *World Neurosurgery* report, has said Martino's surgery may have had "nonspecific effects" on the areas that store and activate episodic memory, and those effects "subsided as the brain readjusted physiologically post-surgery."

Another level, procedural memory, explains what might seem like the most incredible aspect of Martino's story—his ability, given a chunk of his brain is gone, to play the guitar with such dexterity and command. Professional musicians and athletes often say they are not conscious of their actions—their fingers flying across a fretboard, or connecting with a 100 mph fastball. That's because those actions, due to years of practice and repetition, are so deeply embedded that performers are not aware of them. These "sensorimotor skills" are stored in procedural memory, associated with the largest anatomical component of the basal ganglia, which resides above the spine in the forebrain's core, central in the control of movements. In Martino's case, the brain structures associated with procedural memory were unaffected by the AVM and lobectomy. The memories were dormant, waiting to be reawakened.

It's noteworthy, say neuroscientists, that embedded memories, whether episodic or procedural, can be unlocked with a single thought or action. Layers of memory are not regimented but interconnected.

Lynn Nadel, a psychologist who specializes in memory at the University of Arizona, read the *World Neurosurgery* report on Martino, and looked at his cognitive tests. He disagreed with the report that Martino "exhibited complete recovery" from amnesia. "All the evidence suggests that he still has the subtle and in some cases not-so subtle deficits that a person with his kind of damage would have," Nadel said. However, he added, it's "very interesting" to consider why Martino was able to remember who he was because it could have turned out that Martino became a jazz expert again without knowing he was one before. Perhaps he was able to retrieve his identity, Nadel said, "because those skills, and the things associated with those skills, were so deeply embedded in his life."

It could be that traces of Martino's identity left after the surgery were bound up with his procedural memory for guitar-playing. Once they were activated by his playing, it made retrieval of episodic and semantic memories possible. Galarza noted in *World Neurosurgery* that it's interesting that a surviving structure of Martino's brain, the left temporal pole, has been proposed to have the function of connecting "visceral emotional responses" with "complex auditory stimuli," or music. Playing the guitar literally struck the chords of Martino's personal life.

One night in the early 2000s, after a Martino concert at the Blue Note jazz club in New York City, the actor Joe Pesci visited the guitarist backstage. Martino was flattered and told Pesci he enjoyed *My Cousin Vinny*, *Goodfellas*, and *Raging Bull*. "You don't remember me, do you?" Pesci said. "I'm going to tell you what you used to drink in 1963 at Small's Paradise." A Grasshopper.

"At the moment he described the drink, a series of images appeared in my mind," Martino wrote in

ANDREW LEPLEY / CONTRIBUTOR

Martino looked at a black void on one of his brain images. "I would say that what is missing is disappointment, criticism, judgment of others."

*Here and Now!* "I flashed back to Small's Paradise; I remembered the bartender and the stage and the position of the instruments that remained on the bandstand in between sets." Back then, Pesci was a singer and guitar player and used to hang out in Small's Paradise, a Harlem club, with Martino, where the two became close friends. But, Martino wrote, "I had forgotten all about that—until he used that word, that name of the drink, which was the trigger for me to reclaim those memories."

**THE INTERPLAY OF MEMORY** is not the only light that Martino's recovery shines on the brain. It illuminates the impact that music, particularly playing an instrument, has on the brain. "Musical activity involves nearly every region of the brain that we know about, and nearly every neural subsystem," wrote neuroscientist

and musician Daniel Levitin in his 2006 book, *This Is Your Brain on Music*. Neuroscientists have shown that musical skill like a sizzling Martino guitar solo requires a suite of neural processes firing in tandem: perceptual, cognitive, motor, and executive. Making a career as a musician is like being a professional body-builder of the mind. "After all, brain is muscle," Galarza said.

Accomplished musicians can expect their auditory and motor cortices, as well as the corpus callosum—the communication bridge between the left and right hemispheres—to beef up in both gray and white matter, which comprise, respectively, all of the brain's neurons and the axons that link them together. It's been shown that a large tract of white matter called the arcuate fasciculus, connecting the regions responsible for the production and perception of sound—the frontal and temporal lobes—is bulkier in singers and instrumentalists than in non-musicians.

A musician's brain is a confirmation of what Santiago Ramon y Cajal, a founder of neuroscience, wrote in 1904. "Every man, if he so desires, can become the sculptor of his own brain."[6] That goes double for a jazz musician. A 2008 neuroscience study showed that jazz improvisation, compared to playing by memory or sheet music, has a profound neuroplastic effect, activating sensorimotor and language areas in a widespread fashion throughout the brain.[7] Neuroscientists are interested in improvisation because it showcases the neural activity of spontaneous creativity. Notably they've found that improvisation also involves the same brain activities as dreaming and meditation; it shuts down executive function areas and inhibits the tendency to self-monitor.

Although Martino has never played a guitar in an MRI machine, it's safe to say that being a master of jazz improvisation for more than 50 years has amplified his neuroplasticity. In his 2014 report, "Jazz Improvisation, Creativity, and Brain Plasticity," Duffau suggested that Martino's language and music functions likely shifted from his left hemisphere to a more distributed orientation, incorporating part of the interior occipital lobe, which is normally dedicated to processing visual information. Duffau even suggested Martino's "jazz improvisation participated in cerebral reorganization (even before AVM bleeding) and served as a cognitive rehabilitation" following his surgery. In other words, being a brain-damaged musician may have helped save his life.[8]

It's not as far-fetched as it sounds. A 2014 study in *Neuropsychology Review* maintained that, "training-related changes that take place in the brains of musicians may have a beneficial effect on their cognitive outcome and recovery following neurological damage." The study examined the medical cases of 35 musicians, including Martino.[9]

Diana Omigie, lead author of the study, and a research fellow at the Max Planck Institute, explained that larger gray matter volumes in motor and auditory regions in musicians than in non-musicians would create a "brain reserve," which "in turn might be enough to fuel relearning or recovery of a musical function." Musical training, she added, "often results in the development of alternative strategies with which the brain is able to solve a musical problem or task," and so those alternative strategies might take over in the event of neural damage. "It is possible that Pat Martino's ability to redevelop his abilities was due in part to the presence of alternative and dormant strategies, which needed to be rediscovered," Omigie said.

Omigie echoes the point that Martino's brain, long before it hemorrhaged or Martino even knew about his tangled veins, reorganized itself in a way that might shield it from damage. "In our review," Omigie said, "we observed that musicians who underwent surgery for early lesion, cerebral malformations, or slow growing tumors, showed a larger likelihood of recovering cognitive function than those who, for instance, had a stroke and therefore suddenly lost a large amount of healthy normally functioning tissue. The reason is that in the case of slow-forming lesions, some reorganization might have occurred such that over time, the musical function was able to transfer to other parts of the brain and leave the damaged portions less necessary."

Some neuroscientists have stated it might be possible that plasticity in an abnormal brain could lead to a musician's originality. "Although the neurological basis of creativity remains speculative, it is tempting to suggest that Martino's lifelong and most likely slowly enlarging AVM resulted in some of his temporal lobe functions being relegated to neural pathways outside the temporal lobe," said neurologist Robert Burton, author of *A Skeptic's Guide to the Mind: What Neuroscience Can and Cannot Tell Us About Ourselves*. "It wouldn't be surprising if alternative anatomic circuitry contributed to Martino's originality as a guitarist in the first place, and provided the basis for a degree of recovery beyond what would normally be expected following a temporal lobectomy."

Whatever brain mechanisms may have led to Martino's revival, both Omigie and Broks, the neuropsychologist who spent months with Martino for the filming of *Martino Unstrung*, felt compelled to add that science couldn't leave out the work and determination of the guitarist himself. "This was an extraordinary recovery, believe me," Broks said.

**TALKING TO MARTINO TODAY** is a pleasure. There is a Zen calmness about him that gives his remarks, which at times veer into tangents like one of his guitar solos, a gentle wisdom. And a hard-earned one. His recovery from surgery to mental health, a "greater purification," he wrote in *Here and Now!*, took 19 years.

In a scene in *Martino Unstrung*, Martino looked at his MRI brain images. As he stared into a black void of his brain, where his left temporal lobe used to be, he commented, "I would say that what is missing is disappointment, criticism, judgment of others—what is missing are all of the dilemmas that made life so difficult. That's what's missing. And to be honest with you, it's beneficial."

Asked to expand, to reflect on the difference between his guitar playing before and after his surgery, Martino said, "My original intentions prior to neurosurgery had a great deal to do with craft and climbing the ladder of recognition by others. It had to do with the desire to achieve five stars as opposed to two stars for the judgment of an album. And then after the neurosurgery, that no longer had any meaning to me. I am more concerned with the reality of the moment, the enjoyment of that moment. I'm more concerned about the players that are with me, about their feelings, about the emanation of compassion and other virtues that we share together in the process. These are the things that I find much more rewarding than my achievement as a famous musician. Now it's just enjoyment and friendship and compassion and concern. It's an enjoyment of all things as opposed to the enjoyment of specific things."

Martino may always have holes in his memory. Memory expert Nadel said Martino's testaments to living in the moment are echoed by other patients who have suffered amnesia due to brain damage, and have lost the ability to recall the past or envision the future. But clinical diagnoses mean little to the guitarist these days.

"The greatest, truest essence of creative productivity is joy," Martino said. "It's a joy witnessed by those who surround it. They are no longer witnessing a craftsman, they're witnessing a human being who's happy about living, who projects that aura." When he performed now, Martino said, he barely felt the guitar in his hands. Improvising a passage in a song was a spiritual journey. "The brain is a funny thing," he said. "It's part of the vehicle, but it's not part of where the vehicle is going. The vehicle will take you there, but it isn't you."

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# 21

**IT'S HARD TO ARGUE** with the claim that we are living in the information age. We have uncovered vast stores of information in our genes, generated even more ourselves, interpreted physical law in terms of information flow—oh, and we're always on our phones. Philosophers like Luciano Floridi have gone so far as to claim that everything is, at its base, information: "what is real is informational and what is informational is real," he writes in his book *The Fourth Revolution* (the previous three being the handiwork of Copernicus, Darwin, and Freud).

But has all this revelry gone a step too far? In the *New York Review of Books*, philosopher John Searle points out that Floridi's book does not offer a definition of information, handing us a thread that threatens to unravel the whole story. What is the difference between a fact and information? Does information need a consciousness to interpret it, and if so, how much information is there, really? And haven't we always been obsessed with information? The world's oldest surviving literature is full of practical information, not interpretive free-verse. Whether you hold with Searle or Floridi, though, this seems beyond debate: Our old notions of information, and our relationship to it, are being challenged like never before.

Welcome to "Information."

—MS

"The dream of organizing the world's information stemmed not from an authoritarian impulse, but from a deeply utopian one."

**ALEX WRIGHT**
"The Future of the Web Is 100 Years Old" p. 114

# Information

THE ANATOMY OF EVERYTHING

# The Man Who Tried to Redeem the World with Logic

*Walter Pitts rose from the streets to MIT, but couldn't escape himself*

**BY AMANDA GEFTER**

**WALTER PITTS WAS USED** to being bullied. He'd been born into a tough family in Prohibition-era Detroit, where his father, a boiler-maker, had no trouble raising his fists to get his way. The neighborhood boys weren't much better. One afternoon in 1935, they chased him through the streets until he ducked into the local library to hide. The library was familiar ground, where he had taught himself Greek, Latin, logic, and mathematics—better than home, where his father insisted he drop out of school and go to work. Outside, the world was messy. Inside, it all made sense.

Not wanting to risk another run-in that night, Pitts stayed hidden until the library closed for the evening. Alone, he wandered through the stacks of books until he came across *Principia Mathematica*, a three-volume tome written by Bertrand Russell and Alfred Whitehead between 1910 and 1913, which attempted to reduce all of mathematics to pure logic. Pitts sat down and began to read. For three days he remained in the library until he had read each volume cover to cover—nearly 2,000 pages in all—and had identified several mistakes. Deciding that Bertrand Russell himself needed to know about these, the boy drafted a letter to Russell detailing the errors. Not only did Russell write back, he was so impressed that he invited Pitts to study with him as a graduate student at Cambridge University in England. Pitts couldn't oblige him, though—he was only 12 years old. But three years later, when he heard that Russell would be visiting the University of Chicago, the 15-year-old ran away from home and headed for Illinois. He never saw his family again.

In 1923, the year that Walter Pitts was born, a 25-year-old Warren McCulloch was also digesting the *Principia*. But that is where the similarities ended—McCulloch could not have come from a more different world. Born into a well-to-do East Coast family of lawyers, doctors, theologians, and engineers, McCulloch attended a private boys academy in New Jersey, then studied mathematics at Haverford College in

ILLUSTRATION BY JULIA BRECKENREID

Pennsylvania, then philosophy and psychology at Yale. In 1923 he was at Columbia, where he was studying "experimental aesthetics" and was about to earn his medical degree in neurophysiology. But McCulloch was a philosopher at heart. He wanted to know what it means to know. Freud had just published *The Ego and the Id*, and psychoanalysis was all the rage. McCulloch didn't buy it—he felt certain that somehow the mysterious workings and failings of the mind were rooted in the purely mechanical firings of neurons in the brain.

Though they started at opposite ends of the socioeconomic spectrum, McCulloch and Pitts were destined to live, work, and die together. Along the way, they would create the first mechanistic theory of the mind, the first computational approach to neuroscience, the logical design of modern computers, and the pillars of artificial intelligence. But this is more than a story about a fruitful research collaboration. It is also about the bonds of friendship, the fragility of the mind, and the limits of logic's ability to redeem a messy and imperfect world.

**STANDING FACE TO FACE,** they were an unlikely pair. McCulloch, 42 years old when he met Pitts, was a confident, gray-eyed, wild-bearded, chain-smoking philosopher-poet who lived on whiskey and ice cream and never went to bed before 4 a.m. Pitts, 18, was small and shy, with a long forehead that prematurely aged him, and a squat, duck-like, bespectacled face. McCulloch was a respected scientist. Pitts was a homeless runaway. He'd been hanging around the University of Chicago, working a menial job and sneaking into Russell's lectures, where he met a young medical student named Jerome Lettvin. It was Lettvin who introduced the two men. The moment they spoke, they realized they shared a hero in common: Gottfried Leibniz. The 17th-century philosopher had attempted to create an alphabet of human thought, each letter of which represented a concept and could be combined and manipulated according to a set of logical rules to compute all knowledge—a vision that promised to transform the imperfect outside world into the rational sanctuary of a library.

McCulloch explained to Pitts that he was trying to model the brain with a Leibnizian logical calculus. He had been inspired by the *Principia*, in which Russell and Whitehead tried to show that all of mathematics could be built from the ground up using basic, indisputable logic. Their building block was the proposition—the simplest possible statement, either true or false. From there, they employed the fundamental operations of logic, like the conjunction ("and"), disjunction ("or"), and negation ("not"), to link propositions into increasingly complicated networks. From these simple propositions, they derived the full complexity of modern mathematics.

Which got McCulloch thinking about neurons. He knew that each of the brain's nerve cells only fires after a minimum threshold has been reached: Enough of its neighboring nerve cells must send signals across the neuron's synapses before it will fire off its own electrical spike. It occurred to McCulloch that this set-up was binary—either the neuron fires or it doesn't. A neuron's signal, he realized, is a proposition, and neurons seemed to work like logic gates, taking in multiple inputs and producing a single output. By varying a neuron's firing threshold, it could be made to perform "and," "or," and "not" functions.

Fresh from reading a new paper by a British mathematician named Alan Turing which proved the possibility of a machine that could compute any function (so long as it was possible to do so in a finite number of steps), McCulloch became convinced that the brain was just such a machine—one which uses logic encoded in neural networks to *compute*. Neurons, he thought, could be linked together by the rules of logic to build more complex chains of thought, in the same way that the *Principia* linked chains of propositions to build complex mathematics.

As McCulloch explained his project, Pitts understood it immediately, and knew exactly which mathematical tools could be used. McCulloch, enchanted, invited the teen to live with him and his family in Hinsdale, a rural suburb on the outskirts of Chicago. The Hinsdale household was a bustling, free-spirited bohemia. Chicago intellectuals and literary types constantly dropped by the house to discuss poetry, psychology, and radical politics while Spanish Civil War and union songs blared from the phonograph. But late at night, when McCulloch's wife Rook and the three children went to bed, McCulloch and Pitts alone would pour the whiskey, hunker down, and attempt to build a computational brain from the neuron up.

Before Pitts' arrival, McCulloch had hit a wall: There was nothing stopping chains of neurons from twisting themselves into loops, so that the output of the last neuron in a chain became the input of the first—a neural network chasing its tail. McCulloch had no idea how to model that mathematically. From the point of view of logic, a loop smells a lot like paradox: The consequent becomes the antecedent, the effect becomes the cause. McCulloch had been labeling each link in the chain with a time stamp, so that if the first neuron fired at time *t*, the next one fired at *t*+1, and so on. But when the chains circled back, *t*+1 suddenly came *before t*.

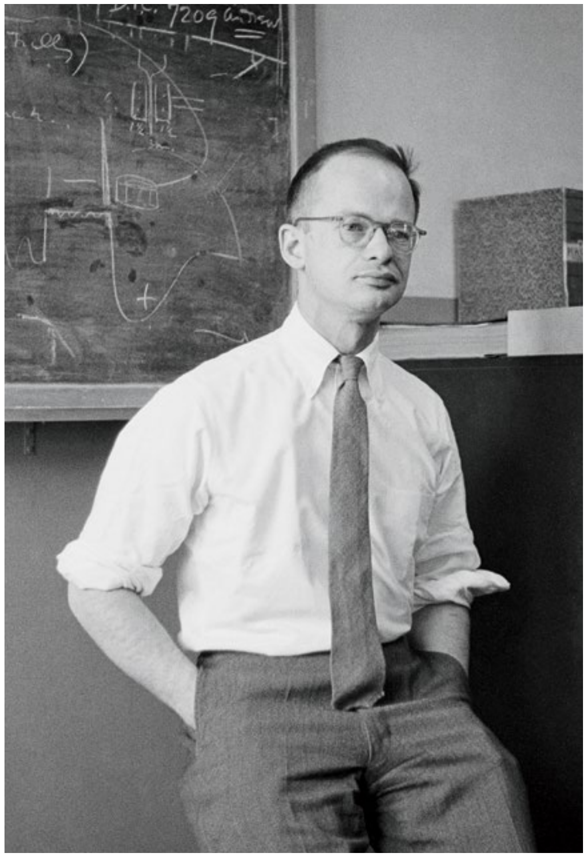
Pitts knew how to tackle the problem. He used modulo mathematics, which deals with numbers that circle back around on themselves like the hours of a clock. He showed McCulloch that the paradox of time *t*+1 coming before time *t* wasn't a paradox at all, because in his calculations "before" and "after" lost their meaning. Time was removed from the equation altogether. If one were to see a lightning bolt flash on the sky, the eyes would send a signal to the brain, shuffling it through a chain of neurons. Starting with any given neuron in the chain, you could retrace the signal's steps and figure out just how long ago lightning struck. Unless, that is, the chain is a loop. In that case, the information encoding the lightning bolt just spins in circles, endlessly. It bears no connection to the time at which the lightning actually occurred. It becomes, as McCulloch put it, "an idea wrenched out of time." In other words, a memory.

By the time Pitts finished calculating, he and McCulloch had on their hands a mechanistic model of the mind, the first application of computation to the brain, and the first argument that the brain, at bottom, is an information processor. By stringing simple binary neurons into chains and loops, they had shown that the brain could implement every possible logical operation and compute anything that could be computed by one of Turing's hypothetical machines. Thanks to those ouroboric loops, they had also found a way for the brain to abstract a piece of information, hang on to it, and abstract it yet again, creating rich, elaborate hierarchies of lingering ideas in a process we call "thinking."

McCulloch and Pitts wrote up their findings in a now-seminal paper, "A Logical Calculus of Ideas Immanent in Nervous Activity," published in the *Bulletin of Mathematical Biophysics.* Their model was vastly oversimplified for a biological brain, but it succeeded at showing a proof of principle. Thought, they said, need not be shrouded in Freudian mysticism or engaged in struggles between ego and id. "For the first time in the history of science," McCulloch announced to a group of philosophy students, "we know how we know."

McCulloch was a confident, gray-eyed, wild-bearded, chain-smoking philosopher-poet who lived on whiskey and ice cream and never went to bed before 4 a.m.

**PITTS WITH LETTVIN** Pitts with Jerome Lettvin and one subject of their experiments on visual perception (1959).



**WALTER PITTS (1923-1969)** Walter Pitts' life passed from homeless runaway, to MIT neuroscience pioneer, to withdrawn alcoholic.

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**PITTS HAD FOUND** in McCulloch everything he had needed—acceptance, friendship, his intellectual other half, the father he never had. Although he had only lived in Hinsdale for a short time, the runaway would refer to McCulloch's house as home for the rest of his life. For his part, McCulloch was just as enamored. In Pitts he had found a kindred spirit, his "bootlegged collaborator," and a mind with the technical prowess to bring McCulloch's half-formed notions to life. As he put it in a letter of reference about Pitts, "Would I had him with me always."[1]

Pitts was soon to make a similar impression on one of the towering intellectual figures of the 20th century, the mathematician, philosopher, and founder of cybernetics, Norbert Wiener. In 1943, Lettvin brought Pitts into Wiener's office at the Massachusetts Institute of Technology (MIT). Wiener didn't introduce himself or make small talk. He simply walked Pitts over to a blackboard where he was working out a mathematical proof. As Wiener worked, Pitts chimed in with questions and suggestions. According to Lettvin, by the time they reached the second blackboard, it was clear that Wiener had found his new right-hand man. Wiener would later write that Pitts was "without question the strongest young scientist whom I have ever met ... I should be extremely astonished if he does not prove to be one of the two or three most important scientists of his generation, not merely in America but in the world at large."

So impressed was Wiener that he promised Pitts a Ph.D. in mathematics at MIT, despite the fact that he had never graduated from high school—something that the strict rules at the University of Chicago prohibited. It was an offer Pitts couldn't refuse. By the fall of 1943, Pitts had moved into a Cambridge apartment, was enrolled as a special student at MIT, and was studying under one of the most influential scientists in the world. It was quite a long way from blue-collar Detroit.

Wiener wanted Pitts to make his model of the brain more realistic. Despite the leaps Pitts and McCulloch had made, their work had made barely a ripple among brain scientists—in part because the symbolic logic they'd employed was hard to decipher, but also because their stark and oversimplified model didn't capture the full messiness of the biological brain. Wiener, however, understood the implications of what they'd done, and knew that a more realistic model would be game-changing. He also realized that it ought to be possible for Pitts' neural networks to be implemented in man-made machines, ushering in his dream of a cybernetic revolution. Wiener figured that if Pitts was going to make a realistic model of the brain's 100 billion interconnected neurons, he was going to need statistics on his side. And statistics and probability theory were Wiener's area of expertise. After all, it had been Wiener who discovered a precise mathematical definition of information: The higher the probability, the higher the entropy and the lower the information content.

As Pitts began his work at MIT, he realized that although genetics must encode for gross neural features, there was no way our genes could pre-determine the trillions of synaptic connections in the brain—the amount of information it would require was untenable. It must be the case, he figured, that we all start out with essentially random neural networks—highly probable states containing negligible information (a thesis that continues to be debated to the present day). He suspected that by altering the thresholds of neurons over time, randomness could give way to order and information could emerge. He set out to model the process using statistical mechanics. Wiener excitedly cheered him on, because he knew if such a model were embodied in a machine, that machine could *learn*.

"I now understand at once some seven-eighths of what Wiener says, which I am told is something of an achievement," Pitts wrote in a letter to McCulloch in December of 1943, some three months after he'd arrived. His work with Wiener was "to constitute the first adequate discussion of statistical mechanics, understood in the most general possible sense, so that it includes for example the problem of deriving the psychological, or statistical, laws of behavior from the microscopic laws of neurophysiology ... Doesn't it sound fine?"

That winter, Wiener brought Pitts to a conference he organized in Princeton with the mathematician and physicist John von Neumann, who was equally impressed with Pitts' mind. Thus formed the beginnings of the group who would become known as the cyberneticians, with Wiener, Pitts, McCulloch, Lettvin, and von Neumann its core. And among this rarified group, the formerly homeless runaway stood out. "None of us would think of publishing a paper without his corrections and approval," McCulloch wrote. "[Pitts] was in no uncertain terms the genius of our group," said Lettvin. "He was absolutely incomparable in the scholarship of chemistry, physics, of everything you could talk about history, botany, etc. When you asked him a question, you would get back a whole textbook ... To him, the world was connected in a very complex and wonderful fashion."[2]

Late at night, McCulloch and Pitts alone would pour the whiskey, hunker down, and attempt to build a computational brain from the neuron up.

The following June, 1945, von Neumann penned what would become a historic document entitled "First Draft of a Report on the EDVAC," the first published description of a stored-program binary computing machine—the modern computer. The EDVAC's predecessor, the ENIAC, which took up 1,800 square feet of space in Philadelphia, was more like a giant electronic calculator than a computer. It was possible to reprogram the thing, but it took several operators several weeks to reroute all the wires and switches to do it. Von Neumann realized that it might not be necessary to rewire the machine every time you wanted it to perform a new function. If you could take each configuration of the switches and wires, abstract them, and encode them symbolically as pure information, you could feed them into the computer the same way you'd feed it data, only now the data would include the very programs that manipulate the data. Without having to rewire a thing, you'd have a universal Turing machine.

To accomplish this, von Neumann suggested modeling the computer after Pitts and McCulloch's neural networks. In place of neurons, he suggested vacuum tubes, which would serve as logic gates, and by stringing them together exactly as Pitts and McCulloch had discovered, you could carry out any computation.

The scientists in the room were floored. And yet, everyone who knew Pitts was sure that he could do it.

To store the programs as data, the computer would need something new: a memory. That's where Pitts' loops came into play. "An element which stimulates itself will hold a stimulus indefinitely," von Neumann wrote in his report, echoing Pitts and employing his modulo mathematics. He detailed every aspect of this new computational architecture. In the entire report, he cited only a single paper: "A Logical Calculus" by McCulloch and Pitts.

By 1946, Pitts was living on Beacon Street in Boston with Oliver Selfridge, an MIT student who would become "the father of machine perception"; Hyman Minsky, the future economist; and Lettvin. He was teaching mathematical logic at MIT and working with Wiener on the statistical mechanics of the brain. The following year, at the Second Cybernetic Conference, Pitts announced that he was writing his doctoral dissertation on probabilistic three-dimensional neural networks. The scientists in the room were floored. "Ambitious" was hardly the word to describe the mathematical skill that it would take to pull off such a feat. And yet, everyone who knew Pitts was sure that he could do it. They would be waiting with bated breath.

In a letter to the philosopher Rudolf Carnap, McCulloch catalogued Pitts' achievements. "He is the most omniverous of scientists and scholars. He has become an excellent dye chemist, a good mammalogist, he knows the sedges, mushrooms and the birds of New England. He knows neuroanatomy and neurophysiology from their original sources in Greek, Latin, Italian, Spanish, Portuguese, and German for he learns any language he needs as soon as he needs it. Things like electrical circuit theory and the practical soldering in of power, lighting, and radio circuits he does himself. In my long life, I have never seen a man so erudite or so really practical." Even the media took notice. In June 1954, *Fortune* magazine ran an article featuring the 20 most talented scientists under 40; Pitts was featured, next to Claude Shannon and James Watson. Against all odds, Walter Pitts had skyrocketed into scientific stardom.

**SOME YEARS EARLIER,** in a letter to McCulloch, Pitts wrote "About once a week now I become violently homesick to talk all evening and all night to you." Despite his success, Pitts had become homesick—and home meant McCulloch. He was coming to believe that if he could work with McCulloch again, he would be happier, more productive, and more likely to break new ground. McCulloch, too, seemed to be floundering without his bootlegged collaborator.

Suddenly, the clouds broke. In 1952, Jerry Wiesner, associate director of MIT's Research Laboratory of Electronics, invited McCulloch to head a new project on brain science at MIT. McCulloch jumped at the opportunity—because it meant he would be working with Pitts again. He traded his full professorship and his large Hinsdale home for a research associate title and a crappy apartment in Cambridge, and couldn't have been happier about it. The plan for the project was to use the full arsenal of information theory, neurophysiology, statistical mechanics, and computing machines to understand how the brain gives rise to the mind. Lettvin, along with the young neuroscientist Patrick Wall, joined McCulloch and Pitts at their new headquarters in Building 20 on Vassar Street. They posted a sign on the door: *Experimental Epistemology.*

With Pitts and McCulloch together again, and with Wiener and Lettvin in the mix, everything seemed poised for progress and revolution. Neuroscience, cybernetics, artificial intelligence, computer science—it was all on the brink of an intellectual explosion. The sky—or the mind—was the limit.

There was just one person who wasn't happy about the reunion: Wiener's wife. Margaret Wiener was, by all accounts, a controlling, conservative prude—and she despised McCulloch's influence on her husband. McCulloch hosted wild get-togethers at his family farm in Old Lyme, Connecticut, where ideas roamed free and everyone went skinny-dipping. It had been one thing when McCulloch was in Chicago, but now he was coming to Cambridge and Margaret wouldn't have it. And so she invented a story. She sat Wiener down and informed him that when their daughter, Barbara, had stayed at McCulloch's house in Chicago, several of "his boys" had seduced her. Wiener immediately sent an angry telegram to Wiesner: "Please inform [Pitts and Lettvin] that all connection between me and your projects is permanently abolished. They are your problem. Wiener." He never spoke to Pitts again. And he never told him why.[3]

For Pitts, this marked the beginning of the end. Wiener, who had taken on a fatherly role in his life, now abandoned him inexplicably. For Pitts, it wasn't merely a loss. It was something far worse than that: It defied logic.

## Pitts, the Poet

McCulloch, Pitts, and Lettvin were all poets at heart and in practice, and McCulloch and Lettvin regularly published their verse. Pitts sent this poem to McCulloch.

"On Quantity of Information"
by Walter Pitts

Random remarks are traced by little boys
In wet cement; synapses in the brain
Die off; renewing uplift glyphs mountain
And valley in peneplane; the mouth rounds noise
To consonants in truisms: Thus expands law
Cankering the anoetic anonymous.
"If any love magic, he is most impious:
Him I cut off, who turn his world to straw,
Making him know Me." So speaks the nomothete
Concealed in crystals, contracting myosin,
Imprisoning man by close-packing in his own kind.
We, therefore, exalt entropy and heat,
Fist-fight for room, trade place, momentum, spin,
Successful enough if life is undesigned.

And then there were the frogs. In the basement of Building 20 at MIT, along with a garbage can full of crickets, Lettvin kept a group of them. At the time, biologists believed that the eye was like a photographic plate that passively recorded dots of light and sent them, dot for dot, to the brain, which did the heavy lifting of interpretation. Lettvin decided to put the idea to the test, opening up the frog's skulls and attaching electrodes to single fibers in their optic nerves.

Together with Pitts, McCulloch, and the Chilean biologist and philosopher Humberto Maturana, he subjected the frogs to various visual experiences—brightening and dimming the lights, showing them color photographs of their natural habitat, magnetically dangling artificial flies—and recorded what the eye measured before it sent the information off to the brain. To everyone's surprise, it didn't merely record what it saw, but filtered and analyzed information about visual features like contrast, curvature, and movement. "The eye speaks to the brain in a language already highly organized and interpreted," they reported in the now-seminal paper "What the Frog's Eye Tells the Frog's Brain," published in 1959.

The results shook Pitts' worldview to its core. Instead of the brain computing information digital neuron by digital neuron using the exacting implement of mathematical logic, messy, analog processes in the eye were doing at least part of the interpretive work. "It was apparent to him after we had done the frog's eye that even if logic played a part, it didn't play the important or central part that one would have expected," Lettvin said. "It disappointed him. He would never admit it, but it seemed to add to his despair at the loss of Wiener's friendship."

The spate of bad news aggravated a depressive streak that Pitts had been struggling with for years. "I have a kind of personal woe I should like your advice on," Pitts had written to McCulloch in one of his letters. "I have noticed in the last two or three years a growing tendency to a kind of melancholy apathy or depression. [Its] effect is to make the positive value seem to disappear from the world, so that nothing seems worth the effort of doing it, and whatever I do or what happens to me ceases to matter very greatly ..."

In other words, Pitts was struggling with the very logic he had sought in life. Pitts wrote that his depression might be "common to all people with an excessively logical education who work in applied mathematics: It is a kind of pessimism resulting from an inability to believe in what people call the Principle of Induction, or the principle of the Uniformity of Nature. Since one cannot prove, or even render probable a priori, that the sun should rise tomorrow, we cannot really believe it shall."

Now, alienated from Wiener, Pitts' despair turned lethal. He began drinking heavily and pulled away from his friends. When he was offered his Ph.D., he refused to sign the paperwork. He set fire to his dissertation along with all of his notes and his papers. Years of work—important work that everyone in the community was eagerly awaiting— he burnt it all, priceless information reduced to entropy and ash. Wiesner offered Lettvin increased support for the lab if he could recover any bits of the dissertation. But it was all gone.

Pitts remained employed by MIT, but this was little more than a technicality; he hardly spoke to anyone and would frequently disappear. "We'd go hunting for him night after night," Lettvin said. "Watching him destroy himself was a dreadful experience." In a way Pitts was still 12 years old. He was still beaten, still a runaway, still hiding from the world in musty libraries. Only now his books took the shape of a bottle.

**WITH MCCULLOCH, PITTS HAD LAID** the foundations for cybernetics and artificial intelligence. They had steered psychiatry away from Freudian analysis and toward a mechanistic understanding of thought. They had shown that the brain computes and that mentation is the processing of information. In doing so, they had also shown how a machine could compute, providing the key inspiration for the architecture of modern computers. Thanks to their work, there was a moment in history when neuroscience, psychiatry, computer science, mathematical logic, and artificial intelligence were all one thing, following an idea first glimpsed by Leibniz—that man, machine, number, and mind all use information as a universal currency. What appeared on the surface to be very different ingredients of the world—hunks of metal, lumps of gray matter, scratches of ink on a page—were profoundly interchangeable.

There was a catch, though: This symbolic abstraction made the world transparent but the brain opaque. Once everything had been reduced to information governed by logic, the actual mechanics ceased to matter—the tradeoff for universal computation was ontology. Von Neumann was the first to see the problem. He expressed his concern to Wiener in a letter that anticipated the coming split between artificial intelligence on one side and neuroscience on the other. "After the great positive contribution of Turing-cum-Pitts-and-McCulloch is assimilated," he wrote, "the situation is rather worse than better than before. Indeed these authors have demonstrated in absolute and hopeless generality that anything and everything ... can be done by an appropriate mechanism, and specifically by a neural mechanism—and that even one, definite mechanism can be 'universal.' Inverting the argument: Nothing that we may know or learn about the functioning of the organism can give, without 'microscopic,' cytological work any clues regarding the further details of the neural mechanism."

This universality made it impossible for Pitts to provide a model of the brain that was practical, and so his work was dismissed and more or less forgotten by the community of scientists working on the brain. What's more, the experiment with the frogs had shown that a purely logical, purely brain-centered vision of thought had its limits. Nature had chosen the messiness of life over the austerity of logic, a choice Pitts likely could not comprehend. He had no way of knowing that while his ideas about the biological brain were not panning out, they were setting in motion the age of digital computing, the neural network approach to machine learning, and the so-called connectionist philosophy of mind. In his own mind, he had been defeated.

On Saturday, April 21, 1969, his hand shaking with an alcoholic's delirium tremens, Pitts sent a letter from his room at Beth Israel Hospital in Boston to McCulloch's room down the road at the Cardiac Intensive Care Ward at Peter Bent Brigham Hospital. "I understand you had a light coronary; ... that you are attached to many sensors connected to panels and alarms continuously monitored by a nurse, and cannot in consequence turn over in bed. No doubt this is cybernetical. But it all makes me most abominably sad." Pitts himself had been in the hospital for three weeks, having been admitted with liver problems and jaundice. On May 14, 1969 Walter Pitts died alone in a boarding house in Cambridge, of bleeding esophageal varices, a condition associated with cirrhosis of the liver. Four months later, McCulloch passed away, as if the existence of one without the other were simply illogical, a reverberating loop wrenched open.

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*Access to historical letters was provided by the American Philosophical Society.*

# Did Grief Give Him Parkinson's?

*These identical twins led virtually identical lives—with one tragic exception*

**BY ROBIN MARANTZ HENIG**

J**ACK GERNSHEIMER MET** my car at the bottom of the lane. He looked good this summery Sunday, rested and tan. The logo on his T-shirt was one he and his brother designed years ago, featuring the name of the town they grew up in, which at the time was celebrating its 150th birthday: "Bernville, Pennsylvania, 1851-2001."

This is a beautiful part of the state, lush green farms in rolling countryside, the Blue Mountains vague in the distance. It's Updike country; the town of Shillington memorialized in John Updike's early short stories is less than half an hour away.

I had driven up to spend time with Jack, who has Parkinson's disease, and his twin brother Jeff, who does not. Because they are identical twins with identical genomes, it may appear to be a mystery that only Jack is sick. Yet scientists have long known that genes alone cannot explain why some people get Parkinson's and others don't. While a handful of genetic mutations are linked to the disease, about 90 percent of cases of Parkinson's are "sporadic," meaning the disease does not run in the family. And twins, even identical twins, don't usually get Parkinson's in tandem. In one of the largest longitudinal twin studies of the disease, Swedish scientists reported in 2011 that of 542 pairs in which at least one twin had Parkinson's, the majority were "discordant," meaning that the second twin was unaffected. The discordance rate was higher for fraternal twins, who are no more alike genetically than any two siblings. But even identical twins had a discordance rate of 89 percent.

So if genes don't explain most cases, how about the environment? Several environmental factors have been linked to Parkinson's, which has been shown to occur at higher-than-expected rates in, for instance, people

PHOTOGRAPHY BY ADAM GOLFER


**BIRDS OF A FEATHER** Identical twins Jack and Jeff Gernsheimer in their graphic arts studio, on their family farm in eastern Pennsylvania. They have been working side-by-side since 1971.

who were prisoners of war in World War II. There is also a higher rate in people who live on farms or who drink well water, probably because of exposure to certain pesticides.

But the environmental connection is precisely what makes Jack and Jeff so interesting. For almost all of their 68 years, they have lived no more than half a mile apart. They have been exposed to the same air, the same well water, the same dusty farm chores, the same pesticides. They built their homes a five-minute walk from each other, on two plots of their father's 132-acre farm in eastern Pennsylvania. And since 1971 they have worked in the same office, their desks pushed together, at a graphic design firm they co-own. All this makes their particular discordancy tougher to explain.

The existence of a pair of twins with identical DNA and nearly identical environments in which only one is sick—that's a researcher's bonanza. Whatever difference can be untangled in the twins' physiology probably relates directly to the disease and its origins. The genome can be held constant; environmental toxins and other exposures can be held constant; what remains, researchers are left to think, might be an odd shift in a particular neural pathway that has a relevant function all its own.

For years, the twins have been active participants in Parkinson's experts' search for answers. Recently, at the New York Stem Cell Foundation, scientists compared cultures of neurons they made from stem cells harvested from Jack and from Jeff. The Jack-derived neurons, they found, differed from the Jeff-derived neurons in how they produce two important brain chemicals: the neurotransmitter dopamine, and an enzyme called beta-glucocerebrosidase. They also differed in a particular molecular signaling pathway, which was found to be deficient in Jack's culture but not in Jeff's. The team's next focus will be to look at genes found not in the nucleus of the twins' brain cells, but in the mitochondria floating around the nucleus.

None of this could have been done without cutting-edge stem cell technology. And none of it could have been done without a pair of identical twins with virtually parallel lives.

It's where those parallel lives diverge, though, that might provide a lasting new insight. Beginning on the day in 1968 when Jack was drafted and Jeff was not, Jack suffered a series of shifts and setbacks that his brother managed to avoid: two years serving stateside in the military, an early marriage, two children in quick succession, a difficult divorce, and finally, in the biggest blow of all, the sudden death of his teenage son.

After these key divergences in their lives, Jack went on to develop not only Parkinson's but two other diseases that Jeff was spared, glaucoma and prostate cancer. The twins place great stock in these divergences, believing they might explain their medical trajectories ever since. Scientists are trying to figure out whether they could be right.

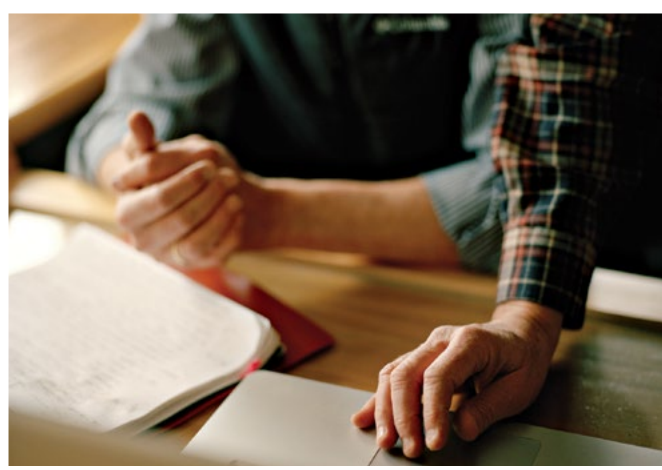
**JACK AND JEFF GERNSHEIMER** look very much alike: tall, slender, with long oval faces and thinning gray hair. But they have different personalities—Jack is introverted, Jeff more gregarious—and different ways of confronting their darkest emotions. "He's stoic," Jeff says about his brother. And while Jack generally is "a mellow guy," he added, in times of his greatest stress he was "probably a pressure cooker inside—but that wasn't apparent to me."

Growing up in Bernville (current population, 956), the twins lived a happy small-town life, playing soccer, basketball, and baseball, joining the marching band (Jeff on trombone, Jack on drums), earning good grades, getting along fine with the other 29 students in their graduating class. They were tethered in work and play, in harmony and disharmony, regularly rotating through what they called an "annoyance cycle": best friends for a while, then arguing about something stupid, then quickly making up and being best friends again. Sometimes the fighting was psychological; when they were in elementary school, Jeff made Jack cry by convincing him, bizarrely, that he was adopted. Sometimes it was physical, as at the memorable family dinner when the teenaged twins ended up wrestling at the dining room table, locked in combat because Jeff said Jack was hogging all the clams.

Their lives diverged between the ages of 18 and 25, tilting their paths off course just enough to remain, forever after, the tiniest bit askew. First they chose different colleges: Jeff went to Moravian College in Bethlehem, about an hour from home; Jack went further away, to Syracuse University. They both reported to the draft board in 1968, but only Jack passed the physical. Jeff, who had had a childhood infection that left him nearly deaf in one ear, was classified 4-F.

The twins were living together in Manhattan in the summer of 1968 when the draft notices came in the mail. Jack was out of town, so Jeff opened both. He was devastated to see that Jack was 1-A. It was sheer dumb luck that had made him fail his physical, Jeff thought; his hearing was particularly bad that day, probably

During one contentious meeting, Jack drove home to get the pistol he had bought to protect Jeff from the "thug." Nothing further happened, and he drove home and put the gun in a safe hiding place.



because he had taken a hot shower that morning and his ears were clogged. In Jeff's mind it was Jack who should have gotten the draft deferral. Jack was the one with the good job at an advertising agency, the steady girlfriend, the grown-up attitude; Jeff was the expendable one, with no real obligations and no immediate prospects. So Jeff considered switching identities. For a few weeks, unbeknownst to his brother, he toyed with the idea of just reporting for duty and saying he was Jacob Gernsheimer, sort of like Don Draper in reverse.

Jack never would have allowed it, of course (and the plan never got past the rumination stage anyway). He was born three minutes earlier and had always acted like the big brother; it was he who rescued Jeff, not the other way around.

When Jack got home from the Army in late 1970, he was already married to his college sweetheart. The following summer the twins started Partners Design, working out of the original farmhouse on the land their father had owned, living together above the studio along with Jack's wife and their new baby daughter, Jessica. A year and a half later, Jack's son Gabriel was born.

The twins' business thrived, and in 1979 Jeff moved into his own home, which he built on his one-third plot on the old family farm out of recycled materials from a Pennsylvania barn. The next year he married Jan Barnett, a teacher from Philadelphia who later admitted that at first she'd had trouble telling her date and his twin apart.

In the mid-1970s, there was trouble on the town zoning board, where Jeff sat as a volunteer. The board voted against the pet project of a local builder, who threatened violence in a way that was convincing enough for Jack, at least, to take seriously. During one particularly contentious meeting, Jack drove home to get the pistol he had bought to protect Jeff from the "thug." He returned to the board meeting, leaving the gun in the car under a floor mat, intending to run back to get it if the builder's threat ever materialized. But nothing further happened, and Jack never had to leap to Jeff's rescue the way he'd pictured it. He drove home and put the gun in a safe hiding place.

**FOR A WHILE, JACK** mistook his Parkinson's symptoms—primarily a profound fatigue that just wouldn't quit—as the late effects of anesthesia, after he had his prostate removed for prostate cancer in 2009. After a few months of feeling exhausted he went to his internist, who said this sounded like something more than a lengthy post-surgical recovery. He referred Jack to a neurologist, who diagnosed Parkinson's disease, a neurological disorder in which cells in a structure of the midbrain called the substantia nigra lose function and stop producing dopamine, the neurotransmitter responsible for many functions, including motor control and the brain's reward system. Typical symptoms include stiffness, tremor, problems with gait, depression, and occasionally cognitive decline.

Around the time of Jack's diagnosis, he was introduced to Susan Solomon through a mutual friend. Solomon, a successful entrepreneur and businesswoman, had recently founded the New York Stem Cell Foundation (NYSCF, pronounced "NIE-sef"), believing stem cells were the fast track to a cure for diabetes (which affected her son) and other diseases.

When Solomon heard that Jack was an identical twin, and that his twin was healthy, she could tell they would make great subjects for her scientists, who use stem cell technology to study a variety of degenerative diseases.

To get a personalized embryonic stem cell, scientists start by taking some of a person's cells, usually skin cells from the upper arm, and growing them in a Petri dish. In another dish, they remove the nucleus from an unfertilized human egg, and replace it with the nucleus of a cell from the skin cell culture in a procedure called nuclear transfer. What they end up with is a human blastocyst that contains the skin cell donor's DNA.

The technique for creating human embryonic stem cells was discovered in 1998 using leftover fertilized eggs from IVF clinics, and was instantly controversial because it involved the creation and destruction of human blastocysts. President George Bush imposed a moratorium in 2001 on federal funding to derive new cell lines for human embryonic stem cell research, so other sources of funding materialized out of necessity. One of these was NYSCF, founded in 2005.

The controversy about stem cell research has cooled somewhat, largely because of the discovery of another way to derive pluripotent cells without using blastocysts. Developed in 2006 in mice, and in humans

**TWISTS OF FATE** Jack and Jeff on a winter field between their Pennsylvania homes, built less than a mile apart. They say a few sharp divergences in their personal lives may well explain their medical fates.

the following year, it involves treating adult skin cells with four specific chemicals (signaling molecules) to turn those cells back to their pluripotent state. This is the method NYSCF scientists used in their study of the Gernsheimer twins.

The study began with Jack and Jeff each undergoing a small punch biopsy on his arm to generate a few thousand skin cells. Then the scientists, led by neurobiologist Scott Noggle, grew the skin cells in two separate cultures and treated them with the signaling molecules. The hardiest of these cells were grown for eight or nine weeks into different pluripotent stem cell lines, a few for each twin.

In nature, these pluripotent cells would then diverge into one of three types of progenitor cells: those that give rise to brain and skin, muscles, or gut. From there, further decision points occur in embryonic development: the progenitor brain cell can develop into either a neuron, say, or a glial cell, either a forebrain neuron or a mid-brain neuron, and on and on toward further refinements. In the lab, scientists can stack the deck using more signaling molecules, forcing the development of whatever cell type they desire.

The beauty of stem cell cultures is that they behave in the dish similarly to how they would in the body. That's what happened in this case. The mid-brain dopaminergic neurons grown from Jack's cells produced abnormally low amounts of dopamine. The Jeff-derived culture produced normal amounts.

But here was the first surprise: even though Jeff showed no clinical signs of Parkinson's or any other neurological disease, the Jeff-derived culture was not exactly normal. Both twins, it turned out, had a mutation on a gene called GBA (a mutation already known to be associated with Parkinson's disease), and as a result, both of their brain cell cultures produced just half the normal amount of an enzyme linked to that gene, beta-glucocerebrosidase. They also both produced three times the normal level of alpha-synuclein, a brain protein usually broken down by a process involving the GBA enzyme. Alpha-synuclein is thought to be related to Parkinson's, possibly by leading to the formation of the toxic lesions known as Lewy bodies that are a hallmark of the disease.

The teens got into a discussion about the scene in which the prisoners are forced to play Russian Roulette.

So rather than answering questions about the twins' discordance, these findings only raised more. Jeff had the same Parkinson's mutation his brother had, and his brain cells in culture behaved just as abnormally in relation to the GBA enzyme and alpha-synuclein. Yet he apparently has been spared. It was a puzzle. The scientists hoped the answer existed somewhere in those two Petri dishes.

**AFTER JACK MET ME** at the bottom of the lane, we drove up together to his house, which he and his second wife, Nancy Wolff, built in 1990, shortly after they were married. Like Jeff's, Jack's house is made of materials from a local barn. It is located on his one-third of the property, just a bit further down the lane from Jeff's. (The twins' younger sister, Sharon, who lives with her husband and their twin daughters in New Jersey, will soon build a house on her portion of the land for when she retires.) Nancy was in the garage, swimming in the indoor pool they had installed a few years ago as part of the project of keeping Jack physically fit. Nancy, a copyright attorney in New York, has a friend who invented Endless Pools, and he gave her one when he heard about Jack's diagnosis, knowing that regular exercise can help stave off the worst symptoms of Parkinson's.

Since 2009, Jack has been on a regimen of L-dopa, which helps with motor symptoms like tremor and rigidity by boosting dopamine in the brain. He moves slowly and sometimes stiffly, but manages to exercise almost every day, either walking around his property or on the treadmill he's had sunken at the bottom of the Endless Pool, swimming, or going to the gym to lift weights or walk the treadmill. He also still goes to work three or four days a week at his and Jeff's design firm, sitting at a desk pushed up against his brother's that looks out over an expanse of woods.

Jack's voice has gotten softer, and he says he has some trouble keeping in mind the sequence of complicated steps, like following directions to somewhere new. He sometimes fails to find the word he's looking for. "That's the worrisome thing, that my memory isn't what it was," he told me. "Though it's hard to know how much of that is the disease, and how much of that is simply aging."

During my visit last summer, Jack and I sat down at the kitchen counter, a cozy spot at one end of the wide-open first floor of his house, overlooking a 3-acre pond fringed with a profusion of orange day lilies. Cautiously, I asked about what happened to his son. All I knew, based on our earlier conversations, was that he had a son who died at 14, and that he and Jeff both think the grief he suffered in the aftermath helps explain the physical burdens he's shouldered ever since. Jack told the story straight, the way he tells everything, looking directly at me and barely blinking, in a quiet voice and without much inflection. The calm gaze, the low volume, the lack of apparent emotion could be symptoms of Parkinson's, but they're also partly the way Jack has always been. He was talking, softly and evenly, about Gabe, but he was also talking about his own residual pain.

The year was 1987. "I was doing some acting at the time," he said, "and I was involved in a piece that dealt with the Vietnam War." The play was *Streamers* by David Rabe, and after Gabe went to see his father perform, "he was anxious to find out more about the war." Like any good father, Jack supported his son's interest, taking him to see *Full Metal Jacket*, renting videotapes so Gabe could watch some of the older Vietnam movies at home.

One of those movies was *The Deer Hunter*, the 1978 film starring Robert DeNiro and Christopher Walken as two soldiers, childhood friends (who were, coincidentally, also from small-town Pennsylvania) who are imprisoned and tortured by the Viet Cong. As Gabe and his friend watched it, they got into a discussion about the scene in which the prisoners are forced to play Russian Roulette. If it were me, Gabe told his friend, I would never just sit there and agonize over it; I would get it over with quickly, I would just do it. And with that, according to the friend, Gabe went to get the pistol he knew his father had hidden away, got the bullets he knew were kept separately, put one in the nine-bullet chamber, spun it once, put it to his head, and shot.

"I blame myself," Jack said, barely audible.

Later, when Jeff came by for lunch at the picnic table out back, we talked some more about Gabe's death. The summer before Gabe shot himself, Jeff and his wife Jan, pregnant at the time, had taken Gabe with them on a vacation to Nantucket. Jeff said it was a wonderful week. At one point Gabe, always something of a risk-taker, concocted a primitive set of wings, with Uncle Jeff's help, out of some old sheets and a few strategically placed boards. Then, wearing a goofy pair of shorts he and Aunt Jan had sewn together out of material festooned with flags, he went running off a sand dune, jumped, and seemed for one short moment to fly.

Jeff's chin quavered and he lost his voice. "I think of Gabe every day," he managed to say. Jack sat at the table, gazing quietly at his mourning brother.

**JACK ALONE** Why Jack (pictured at home, and headed out for an afternoon walk) and not his twin brother Jeff, has Parkinson's remains a mystery to researchers. Still, both brothers continue to participate in leading-edge studies of the disease.

**TO THE TWINS,** the "pressure cooker" way Jack dealt with stress, most grievously the loss of Gabe, helps explain Jack's added health burden today: the Parkinson's, the glaucoma, the prostate cancer. Jeff said those might be "physical manifestations" of the different ways they handled stress. "Jack internalizes more than I do," he said.

The connection between stress and disease is a lively research topic, as scientists discover how life experiences alter gene expression and contribute to diseases ranging from diabetes to the common cold. But while statements about the "gene-environment interaction" have become a familiar trope, the twins' story offers a different way to look at it. Traditionally, "environment" is defined as external events that occur over a lifetime, or the impact of those events at the molecular level, which is in the realm of epigenetics. According to Steve Cole, a professor of medicine at the University of California, Los Angeles School of Medicine, the relevant aspect of "environment" in terms of the twins might be something more interior and personal.

Cole is interested in "the environment we create in our heads"—not what literally happens, but how the individual experiences what happens. "That is the most interesting aspect of the story of the twins," he told me recently. "Their experiential environments."

Jack and Jeff's understanding of their respective experiential environments is that Jack's is the more stressful. And some research suggests this might have particular relevance to Parkinson's disease. In 2002 at the University of Pittsburgh, neuroscientists subjected rats to stress through physical restraint, and found that the stressed rats were more likely than non-stressed rats to experience damage to their dopamine-producing neurons when later injected with a toxin. This might be an indication of "neuroendangerment," lead author Michael Zigmond told me recently: Rather than stress producing damage directly and immediately, it might increase the vulnerability of dopamine-producing cells to a subsequent insult.

Zigmond, a professor of neurology at Pitt, said neuroendangerment is tricky to study, because the connection between early-life stress and late-life disease can be easy to miss. "The stress can occur at one point in time," he said, "and the impact on neurodegenerative disease—Parkinson's disease and also stroke and Alzheimer's disease—can happen years later. By then the connection between the early stress and the neurological disease may be forgotten." He hazards a guess, based only on the information he heard from me, that something like this might be going on in Jack's case.

Or maybe Jack's Parkinson's is linked to an intermediate step: chronic inflammation. That's the mechanism by which stress can lead to neurodegeneration, according to Cole. The inflammatory immune response is "baked in by evolution to help defend us when are feeling threatened," he told me. "It probably made sense for millions of years, when the threat correlated with microbes. Unfortunately, the inflammation that drives that priming comes with some penalties"—among them, damage to the brain cells. Cole said it's "plausible" to think the differences in the twins' medical status can be traced to differences in their life histories, which in turn led to differences in their immune systems. Exhibit A: Jack has psoriasis, a skin condition linked to autoimmunity and chronic inflammation. Jeff does not.

> When they try to explain their medical histories, the twins return to the tyranny of small differences.

**THESE DAYS, IT'S JEFF** who protects Jack. Instead of splitting the workload at their design firm 50-50 the way they used to, Jeff does most of it now. That's been the hardest adjustment, because Jack was the better designer. "But I think at this point maybe I'm more objective about a design and a solution," Jeff said. "At this point, maybe more than in the past, it might be that he says, 'I nailed it,' and we look at it and I have to say, 'Um, I don't think that you did.'"

In solidarity with his twin, Jeff also signs up to be the normal control in whatever Parkinson's study he hears about, hoping to help uncover some new information in time to help Jack. He gets MRI scans, gets hooked up to EEG machines, takes dozens of pencil and paper tests to measure his cognitive abilities, and dozens of physical challenges to measure his balance and muscle control. He's probably the most thoroughly investigated healthy man he knows.

The search for answers to the puzzle of Jeff's good health, despite the abnormalities in the Petri dish, continues. Late last year, the NYSCF scientists, led by Noggle, described their work on the twins' cells (as well as the cells of one other Parkinson's patient and four controls) in the journal *Cell Reports*. They were able to find a few functional differences between Jack's cells and Jeff's, and to highlight abnormalities in one particular pathway involving the enzyme MAO-B (monoamine oxidase-B).

After identifying the GBA mutation the twins share, and observing high alpha-synuclein levels in both cultures, the scientists searched harder for what might differentiate Jack's and Jeff's functioning brains. There was a chance, they thought, that one might have developed a new, tiny mutation during his lifetime that the other had not. This led them to a closer study of their genomes.

First the team screened for the 66 mutations known to be associated with Parkinson's. But they found nothing other than the GBA mutation they'd already found. Next they screened for the 39,000 known "single nucleotide variants" in the genome that only one twin might have had. SNVs are instances in which a single nucleotide—among the three million or so in the human genome—has been switched, deleted, or duplicated. They found 11 SNVs, including nine linked specifically to Parkinson's disease, but they found them in both twins—meaning SNVs could not explain why Jack was sick and Jeff was not.

The next series of tests finally uncovered a relevant difference: Jack had abnormally high levels of MAO-B, which is involved in the breakdown of dopamine. Jeff's MAO-B levels were only slightly above normal.

This was provocative. It suggested a possible molecular mechanism by which stress could lead to neurodegeneration: via monoamine oxidase, which sits on the outer membrane of the mitochondria and has been linked to the oxidative stress that can kill off brain cells.

What's nice about this finding is that it suggests a possible therapy for Parkinson's. There are already drugs on the market, called MAO-B inhibitors, that treat high levels of the enzyme. When Noggle's team introduced one such MAO-B inhibitor, Rasagiline, into the Jack-derived brain cell culture, they reduced MAO-B levels and, more important, increased the amount of dopamine those brain cells produced.

Now the question is whether Rasagiline can work clinically. Some studies have shown improvement of Parkinson's symptoms with Rasagiline at low doses, but not at high doses. Other studies indicate that patients given MAO-B inhibitors have higher mortality rates overall.

So it's too soon to recommend any kind of treatment change for Jack, or for anyone else with Parkinson's disease. But the findings do show something interesting about Jeff: that it's possible to have one or more genetic mutations associated with a condition, yet somehow to avoid whatever else transforms a genetic tendency to a genetic destiny. And they suggest a next step for research on the twins—studying their mitochondrial genes.

Identical twins occasionally have different sets of mitochondrial genes (of which there are just 37, versus 22,000 or so in the whole genome), if the mitochondria in the cell body divide up unevenly when the egg splits in two. The exact rate at which this uneven split occurs hasn't been studied in detail, said Noggle. But based on a preliminary look at Jack and Jeff's mitochondrial DNA, he said there's a "pretty high likelihood" that theirs might not be identical. If that pans out, he said, his team might be on the road to finding "a potential explanation for susceptibility not just to Parkinson's, but to other neurodegenerative diseases" like Huntington's and Alzheimer's. The NYSCF scientists won't know anything for at least a year, Noggle added. That's the way this kind of knowledge accrues—much more slowly than anybody would like.

As for Jack and Jeff, when they read the *Cell Reports* paper, they tried not to feel disappointed. Its take-home message appeared to be that not much can be done at the moment to ameliorate Jack's symptoms (nor to prevent them from developing in Jeff, though he insists he never worried about that; all his concern for the future, he says, is focused on Jack). "Unfortunately," Jeff said, "there's a fair amount of testing still to be done."

For now, when they try to explain their divergent medical histories, the twins return to the tyranny of small differences: Jack's more introverted personality, rockier life, quieter grieving style. In this belief they tap into the suspicions of a small cadre of neuroscientists trying to pinpoint the connection between stress and neurodegeneration. Maybe the twins are on to something the scientists are on the verge of identifying. Or maybe the brothers who have been all but inseparable are trying to protect themselves from the cruel realization that fate can unspool in dissonant ways.

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# The Future of the Web Is 100 Years Old

*In the debate between structure and openness, 19th-century ideas are making a comeback*

**BY ALEX WRIGHT**

**THE EARTH MAY NOT BE FLAT**, but the web certainly is.

"There is no 'top' to the World-Wide Web," declared a 1992 foundational document from the World Wide Web Consortium—meaning that there is no central server or organizational authority to determine what does or does not get published. It is, like Borges' famous Library of Babel, theoretically infinite, stitched together with hyperlinks rather than top-down, Dewey Decimal-style categories.[1] It is also famously open—built atop a set of publicly available industry standards.

While these features have connected untold millions and created new forms of social organization, they also come at a cost. Material seems to vanish almost as quickly as it is created, disappearing amid broken links or into the constant flow of the social media "stream." It can be hard to distinguish fact from falsehood. Corporations have stepped into this confusion, organizing our browsing and data in decidedly closed, non-transparent ways. Did it really have to turn out this way?

The web has played such a powerful role in shaping our world that it can sometimes seem like a *fait accompli*—the inevitable result of progress and enlightened thinking. A deeper look into the historical record, though, reveals a different story: The web in its current state was by no means inevitable. Not only were there competing visions for how a global knowledge network might work, divided along cultural and philosophical lines, but some of those discarded hypotheses are coming back into focus as researchers start to envision the possibilities of a more structured, less volatile web.

**BY THE LATE 19TH CENTURY**, the modern information age had already begun. The industrialization of the printing press, coupled with the introduction of cheap rag paper, had dramatically altered the economics of publishing. Much of Europe and North America was awash in data. Daily newspapers, cheap magazines,

ILLUSTRATION BY PETE RYAN

and mass-market novels all emerged during this period, along with a flurry of institutional reports, memos, and all kinds of other printed ephemera.

Meanwhile, new communications technologies like the telegraph and telephone were cropping up. Tram and railway lines were proliferating. An increasingly internationalized postal service sped the flow of data around the globe. By 1900, a global information network had already started to take shape.

The industrial information explosion triggered waves of concern about how to manage all that data. Accomplished librarians like Melvil Dewey (of Decimal System fame), Sir Anthony Panizzi of the British Library, and Charles Cutter of the Boston Athenaeum all began devising new systems to cope with the complexity of their burgeoning collections. In the fast-growing corporate world, company archivists started to develop complex filing systems to accommodate the sudden deluge of typewritten documents.

Among these efforts, one stood out. In 1893, a young Belgian lawyer named Paul Otlet wrote an essay expressing his concern over the rapid proliferation of books, pamphlets, and periodicals. The problem, he argued, should be "alarming to those who are concerned about quality rather than quantity," and he worried about how anyone would ever make sense of it all. An ardent bibliophile with an entrepreneurial streak, he began working on a solution with his partner, a fellow lawyer named Henri La Fontaine (who would later go on to join the Belgian Senate and win the Nobel Peace Prize): a "Universal Bibliography" (*Repertoire bibliographique universel*) that would catalog all the world's published information and make it freely accessible.

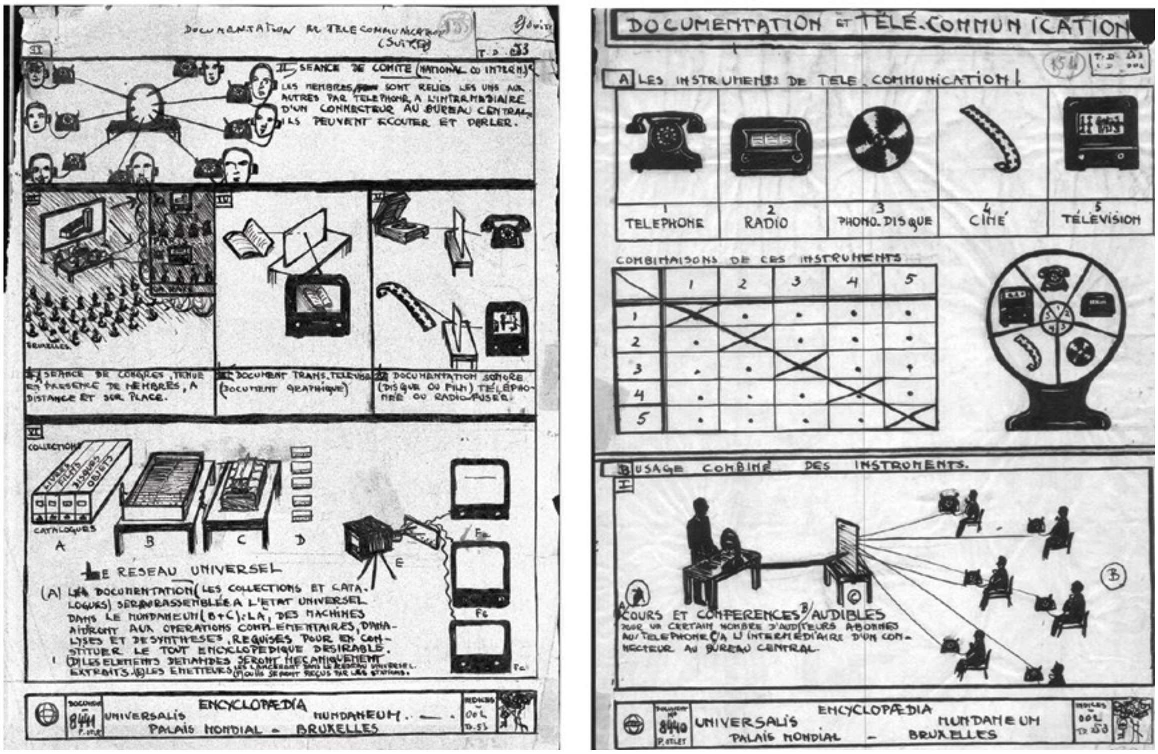
The project won Otlet and La Fontaine a Grand Prize at the Paris World Expo of 1900, and attracted funding from the Belgian government. It would eventually encompass more than 16 million entries ranging from books and periodicals to newspapers, photographs, posters, and audio and video recordings, all painstakingly recorded on individual index cards. Otlet even established an international network of associations and a vast museum called the World Palace (*Palais Mondial*) or Mundaneum, which at one point occupied more than 100 rooms in a government building.

Otlet's Mundaneum presented an alternative vision to today's (nominally) flat and open web by relying on a high degree of bibliographical control. He envisioned a group of trained indexers managing the flow of information in and out of the system, making sure that every incoming piece of data would be properly categorized and synthesized into a coherent body of knowledge. To this end, he and La Fontaine developed a sophisticated cataloging system that they dubbed the Universal Decimal Classification. Using the Dewey Decimal System as its starting point, it started with a few top-level domains (like Philosophy, Social Sciences, and The Arts), which could then be further divided into a theoretically infinite number of sub-topics. This in itself was nothing new, but Otlet introduced an important new twist: a set of so-called "auxiliary tables" that allowed indexers to connect one topic to another by using a combination of numeric codes and familiar marks like the equal sign, plus sign, colon, and quotation marks. So, for example, the code 339.5 (410/44) denoted "Trade relations between the United Kingdom and France," while 311:[622+669](485) meant "Statistics of mining and metallurgy in Sweden."

The dream of organizing the world's information stemmed not from an authoritarian impulse, but from a deeply utopian one.

Otlet hoped that this new system would allow for a grand unification of human knowledge, and entirely new forms of information. But neither he nor his Mundaneum survived the ravages of World War II. After invading Brussels, the Nazis destroyed much of his life's work, removing more than 70 tons worth of material and repurposing the World Palace site for an exhibition of Third Reich art. Otlet died in 1944, and has remained largely forgotten ever since.

Otlet was not alone in his grand vision for a carefully




**ALL THE WORLD'S INFORMATION** An unpublished drawing by Paul Otlet from the Encyclopaedia Universalis Mundaneum papers details part of his organization system (1930s).

cataloged global network. The English novelist H.G. Wells—a devout socialist, pacifist, and feminist (not to mention ardent promoter of free love)—wrote a series of popular essays that he eventually published in 1938 under the title *World Brain*.

With Europe standing on the brink of war, he called for a new, deeply ontological approach to managing conflict. "All the distresses and horrors of the present time are fundamentally intellectual," he wrote. "The world has to pull its mind together."[2] Like Otlet, he saw this undertaking as a central component of a grander, utopian scheme. He envisioned a vast new "encyclopedia" as the distributed brain of a new world order, in which a centralized global information agency would employ an army of technocrats (or "samurai," as he called them) to curate, classify, and disseminate humanity's collective knowledge store around the globe.

Other important European thinkers like the German chemist and Nobel laureate Wilhelm Ostwald—who envisioned an Otlet-like universal knowledge repository called "The Bridge" (*Die Brücke*)—and his protégé Emanuel Goldberg—who invented an early microfilm indexing tool—also explored the possibilities of new, index-driven methods for organizing and distributing the world's information.

All of these proposals were, first and foremost, managed systems, closely curated collections of knowledge that would have required a high degree of systematic control. And for the most part, they were situated squarely in the public sector, with little role for private enterprise. They emerged in an era of industrialization, when many writers saw great hope in the possibilities

Where Otlet and Wells envisioned publicly funded, trans-national organizations, we now have an oligarchy of public corporations.

of scientific management to improve the human condition; and in a time of war, when many thinkers hoped that a more orderly system would serve as a bulwark against the possibility of international conflict.

In other words, the dream of organizing the world's information stemmed not from an authoritarian impulse, but from a deeply utopian one. In the United States, though, a very different kind of utopia was being imagined.

**ACROSS THE ATLANTIC**, an alternative vision of computing was taking shape, driven by a deeply humanistic, individualistic, and American impulse. That vision found its earliest expression in an essay published by Vannevar Bush, a prolific inventor and sometime advisor to President Roosevelt during WWII. In "As We May Think," first published in *The Atlantic* in 1945, Bush proposed a purely hypothetical machine called the Memex: a kind of souped-up microfilm reader that has since become one of the platonic objects of the networked age. The Memex would allow its user to search across a large body of documents stored on film, then create associations—"links"—between them.

Like Otlet and the others before him, Bush recognized the urgent problem of information overload. "The investigator is staggered by the findings and conclusions of thousands of other workers," he wrote, "conclusions which he cannot find time to grasp, much less to remember, as they appear." Unlike Otlet, however, Bush saw no need for an army of indexers to keep track of the world's information. He pointed out what he called "the artificiality of systems of indexing."[3]

Bush argued that the human mind operates "by association," not indexing. And so he proposed a system that would not impose any particular classification system, but would instead allow the user to create "associative trails" that would ultimately be made visible to other users. The essay proved wildly popular, especially after it was reprinted in *Life* magazine. That version of the essay found its way into the hands of a young Navy officer named Douglas Engelbart, then stationed in the Philippines, who found Bush's vision so inspiring that he chose to devote much of the rest of his life to realizing it. Engelbart eventually landed a position at the Stanford Research Institute, where he attracted the attention of J.C.R. Licklider, professor at the Massachucetts Institute of Technology and then-new head of the Defense Department's Advanced Research Projects Agency (ARPA, later renamed DARPA).

Engelbart worked in the 1960s San Francisco Bay Area, where an anti-institutionalist counterculture was then reaching its zenith (at one point he even experimented with LSD). The culture stood in stark contrast to the orderly, institutional tendencies of Otlet and Wells. Where Europeans were turning to their institutions in a time of crisis, many Americans were growing up in a value system that emphasized individualism and personal liberation. It was in this milieu that Licklider, Engelbart, and others began laying the foundations for the web we know today.

With Licklider's support, Engelbart began work on a proto-hypertext tool that eventually came to be known as the oN-Line System. In 1968, he gave a

**THE PAPER GOOGLE** Paul Otlet at the Universal Bibliographic Repertory in Brussels, which grew into the Mundaneum.

demonstration of the system at the Herbst Theater in San Francisco, an event that has since gone down in computer history lore as The Mother of All Demos. Engelbart presented a startlingly far-sighted concept, complete with a word processor, a method for creating hyperlinks between documents, and live video conferencing, all operated by a keyboard and a rudimentary mouse (another Engelbart invention).

The 1960s novelist and Merry Prankster Ken Kesey later dubbed the system "the next thing after acid." By the early 1970s, a "People's Computer Center" had appeared in Menlo Park, California, providing access to rudimentary computer tools. Personal liberation, empowerment, and revolutionary rhetoric—all deeply American traits—shaped the attitudes of many early personal computer hobbyists, and have persisted ever since in the cultural fabric of the modern technology industry.[4]

The utopianism of that era found a particularly colorful expression in the work of Ted Nelson, a decidedly unconventional computing entrepreneur who promoted his own alternative vision of hypertext (a word he coined in 1963). A former filmmaker turned Harvard sociology student, Nelson developed a fascination with computers in the 1960s that led him to self-publish a series of visionary, over-the-top manifestos like *Computer Lib* and *Dream Machines*. These presented startlingly original concepts, with names like "Thinkertoys," "Indexing Vortexes," and "Window Sandwiches," that pointed the way toward a radically personalized form of networked computing.

In his masterwork *Literary Machines*, published in

1981, Nelson proposed something called Xanadu. Taking its name from Samuel Taylor Coleridge's opium-fueled depiction of Kublai Khan's "pleasure dome," Xanadu was a "universal data structure to which all other data structures will be mapped," enabling millions of users to create and share their original written and graphical material.[5] Though Nelson never realized his ambitions for Xanadu, it would provide direct inspiration for Tim Berners-Lee's eventual creation of the World Wide Web.

Like many of his kindred spirits from the 1960s, Nelson took a strong dislike to centrally managed systems. "From earliest youth I was suspicious of categories and hierarchies," he wrote. He was suspicious, too, of large institutions, and especially the university system, which "imbues in everyone the attitude that the world is divided into 'subjects'; that these subjects are well-defined and well-understood; and that there are 'basics,' that is, a hierarchy of understandings." The explosive growth of the web that would come 30 years later would have the unmistakable stamp of Nelson's democratic computing ideal.

**TODAY'S WEB SEEMS TO EXIST** in a state of perpetual discord. There is a constant publishing and unpublishing, amid which we sometimes seem to be teetering on the brink of mass cultural amnesia. The lack of intellectual property controls has created massive—and avoidable—disruption for authors, musicians, and other members of the creative trades (although it's worth noting that Nelson's Xanadu proposed solutions for intellectual property concerns). The lack of stable identity management controls has ushered in the age of spam, phishing, and all manner of malware.

As a result, most of us rely on for-profit companies to make the web safe, useful, and usable. Today, Google and a handful of other major Internet corporations like Facebook, Twitter, and Amazon fulfill much the same role that Otlet envisioned for the Mundaneum—channeling the world's intellectual output. Google freely excludes sites from its index for reasons that it is under no obligation to disclose—the secrets of the Googlebot are Delphic mysteries known only to its inner circle of engineers. An increasing number of web users rely on keyword searching and timelines, like Facebook's, as their primary interfaces. Where Otlet and Wells envisioned publicly funded, trans-national organizations, we now have an oligarchy of public corporations.

While the web may be flat and open in both the public imagination and in the founding rhetoric of the World Wide Web Consortium, a truly flat web may have been just as much of an unreachable utopia as Otlet's universal bibliography. More than a century after Otlet began work on his Mundaneum, the Consortium has begun to consider a new hierarchy that is remarkably Otlet-like in spirit. In May 2001, Tim Berners-Lee, the Consortium's director, published a paper in *Scientific American*, along with two co-authors, proposing a so-called "web of data," called the Semantic Web. It uses metadata, marked-up descriptions of content that follow a consistent set of rules (something like a library classification scheme). By allowing for the consistent use of ontologies, or standardized definitions of topics, content types, and relationships, the Semantic Web promises to make it easier to combine data from disparate sources.[6] The Semantic Web uses a data model known as the Resource Description Framework (RDF) to encode subject-predicate-object relationships—in much the same way that Otlet's Universal Decimal Classificiation used auxiliary tables to allow for the encoding of links between topics, as the historian of science Charles van den Heuvel has pointed out.

Just as Otlet's ideas of centralized hierarchy encountered stiff opposition in his day, so too has the Semantic Web. Some have argued that the Semantic Web amounts to a betrayal of the principles that made the web successful in the first place. In a widely circulated 2005 essay, "Ontologies are Overrated," technology pundit Clay Shirky argued that the Semantic Web was doomed to failure. "The more you push in the direction of scale, spread, fluidity, flexibility," he wrote, "the harder it becomes to handle the expense of starting a cataloging system and the hassle of maintaining it, to say nothing of the amount of force you have to get to exert over users to get them to drop their own world view in favor of yours." Shirky's solution? Crowdsourcing. "The only group that can categorize everything," he wrote, "is everybody."[7]

Web pundit David Weinberger has also given eloquent voice to the anti-hierarchical ethos of the web, arguing that we "have to get rid of the idea that there's a best way of organizing the world." Rather than rely on institutional controls, he believes that the web's messiness is an inherent virtue. "Filter on the way out, not on the way in," he writes, predicting the emergence of what he calls a "third order" of knowledge, one not constrained by the physical limitations of paper, nor encumbered by layers of institutional gatekeepers.[8]

Shirky and Weinberger's critiques point toward important practical challenges that are not easily solved. The question of who might "own" the Semantic Web is a thorny problem. Protocols and standards need an administrative infrastructure to be sustained—as Otlet learned through bitter experience. But there may be a third way. A burgeoning "Linked Data movement" is exploring how to automate the classification process by having computers crawl the web and create machine-generated ontologies, rather than relying on the manual curation of experts. The army of catalogers that Otlet and Wells envisioned may never materialize, but they may not need to: An army of searchbots and algorithms may just do the job instead.

Should the web remain free, flat, and open? Or would a more controlled and curated environment lead, paradoxically, to greater intellectual freedom? These questions can only be completely understood in a historical context, as the latest installment in centuries-old debates about hierarchy and access, efficiency and freedom, institutions and the individual. While it's easy to give in to the temptations of historical exceptionalism and view today's web as the pinnacle of humanity's inexorable march towards liberation, variations on this dialogue have been swirling since before the dawn of the industrial revolution. At 25 years old, the web has plenty of growing up to do.

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# Issue Index

# Janna Levin

*Astrophysics Professor at Barnard College of Columbia University and author of* A Madman Dreams of Turing Machines *reflects on the themes in* Nautilus

**INTERVIEW BY KEVIN BERGER**

### ON ILLUSIONS

We are reliant on sensory information, which creates impressions of the world that are most illusory. We think that physics, which tries to get beyond these illusions, is the province of geniuses, that only geniuses think about this stuff and we have no right to ask foolish questions. But the best questions are always the most obvious ones. It's an illusion this table is solid. It's made up of mostly empty space. Our eyes are sensitive to a wavelength of light that is too big to penetrate the empty space in the atoms. So why doesn't my hand go right through the table? There's an electromagnetic interaction that stops it. Our senses always smooth over deeper truths about the world. We're just simple animals, like all other animals. We see colors because we eat fruit and other animals don't see those colors because they eat other things. It's all evolutionary biology at the end of the day.

### ON CREATIVITY

I'm interested in constrained creativity. Physics is a very particular form of constrained creativity and so is art. James Turrell sets out to make a work purely out of light, with not one piece of hardware visible. That's a serious constraint. If he had lessened his constraint, his work wouldn't have been as powerful. A physicist has to do the same. You study black holes in purely classical form, ignoring quantum mechanics. You come up with general relativity, and have this whole playground, and so do beautiful work inside that context. If you're sloppy about your constraints and say I'm going to let quantum mechanics apply right here but not over there, you're gonna have an ugly mess. So to do good work as an artist or physicist, you have to choose your limits.

### ON INFORMATION

As physicists, we always want to reduce information to the lowest fundamental level. You could say we're nothing more than mathematical objects. Nothing else exists. And maybe you'd be right. But sometimes that's not what we want to understand as human beings. If I'm worried about a personal relationship, I'm not going to find relief in quantum information. My feelings might be triggered by some neurological reaction, and that might have a quantum origin. But that's not the information I need to understand my reactions or theirs. So which is the real information? It all depends on the context. Even though everything can be classified as information, it only has meaning and importance in a context that makes sense to us—which brings us back to our illusions! Our illusions aren't entirely untrue, just true at a different level.

ILLUSTRATION BY ANDY FRIEDMAN


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