

NAUTILUS



54 **THE UNSPOKEN**
After words

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The essential ingredient

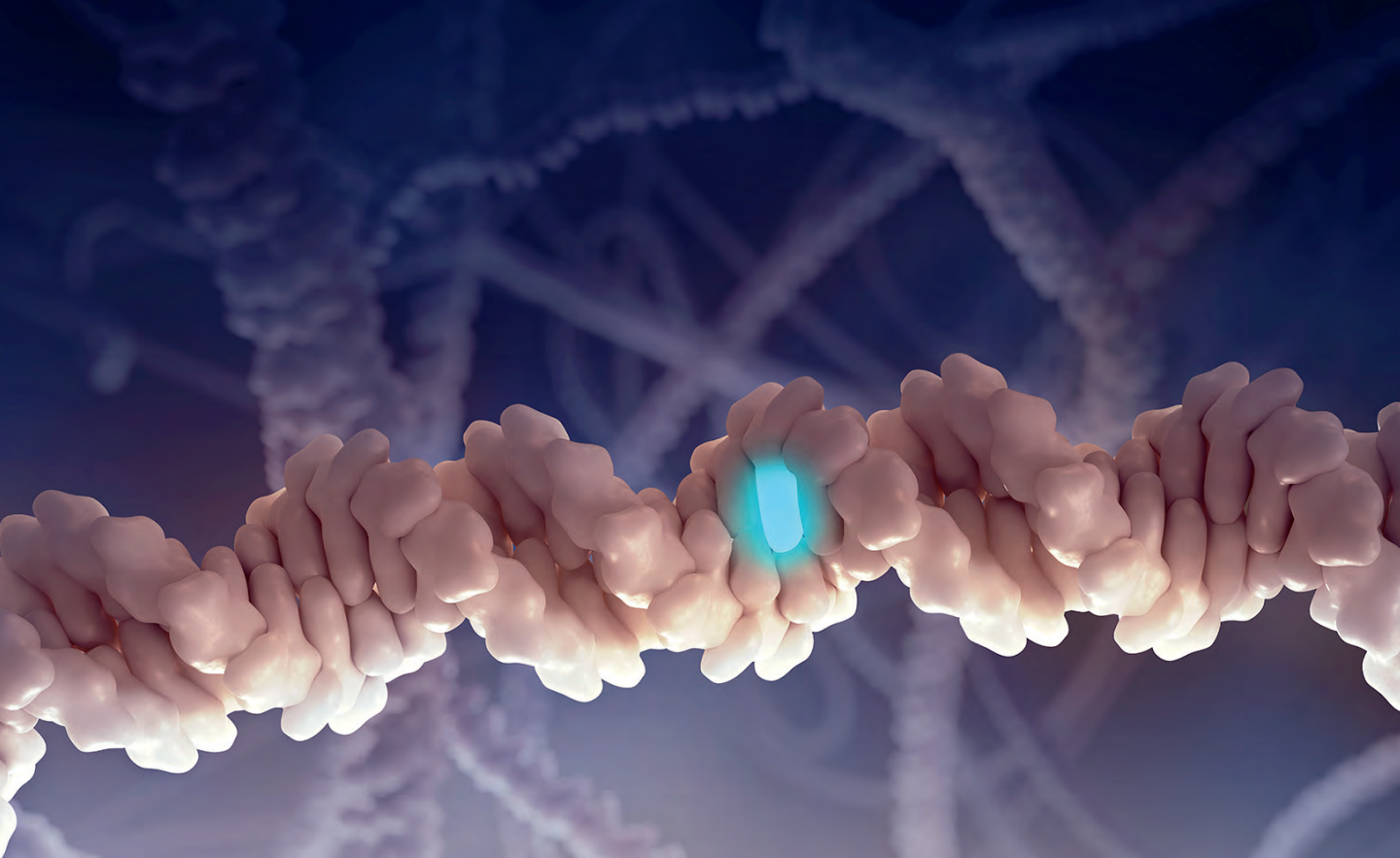
The Evolution of Syntax
HOW WRITING CHANGED LANGUAGE p.20

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Say Again

IN THE SOUTH PACIFIC, a thousand-odd miles east of Australia, is an island archipelago called Vanuatu. There is much to distinguish it—frequent earthquakes, active volcanoes, an indigenous flying fox—but nothing quite equal to its linguistic history.

It is, per-capita, the most linguistically diverse place on Earth. And, in February 2018, researchers led by a team at the Max Planck Institute for the Science of Human History used genomic data to show that, at some point in its history, its indigenous languages persisted during a time that its population's genetic ancestry was entirely replaced by immigration.

The study reminds us that the history and evolution of language, while connected to our biological evolution, is also very much separate from it. Languages have their own Darwinian story, changing or resisting change according to the details of their own fitness landscape.

In this issue's cover story, linguist Julie Sedivy tells us the story of the evolution of a key characteristic of language: sentence complexity. The chestnut that today's generation is incapable of putting together a sentence has been "current" since at least the 1300s, when the writer William Langland complained about it. And the average English sentence length has indeed fallen by half since the 17th century.

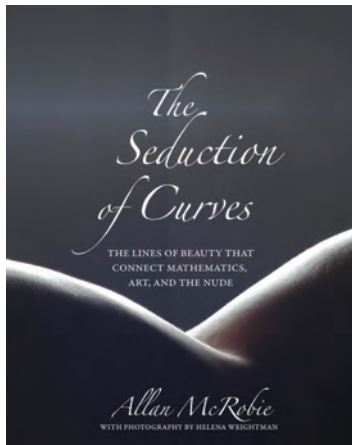
Sedivy explains that declines like these—and the ascents that precede them—can be understood in part by considering changes in the technology of language and the communities it serves. Chief among these technologies is writing, which freed us from the constraints of our memory and boosted complexity. The rise of scientific communities, curiously, tended to reduce sentence complexity because specialized common knowledge allowed complexity to be encoded into words instead of grammar.

It is interesting to note the opposing trends in word and sentence length. While sentence length has been falling over the past centuries, word length has been increasing (by about 20 percent from 1700 to the late 1990s, in English). Is our modern media echo-chamber creating an even greater insularity that will diminish language complexity, or is it unifying communities and producing the opposite effect?

The jury is still out, but, as always, our language is changing: American English word length fell sharply from the late 1990s through today.

Welcome to the November/December 2017 *Nautilus* print edition.

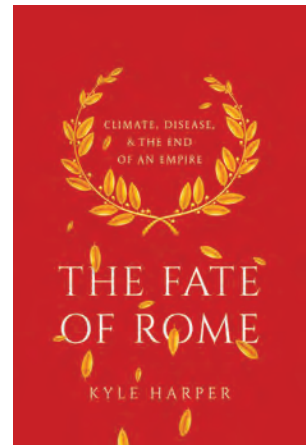
—Michael Segal
Editor in Chief



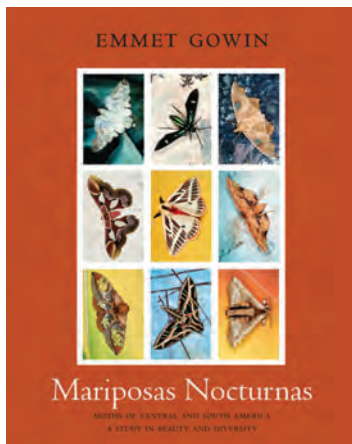
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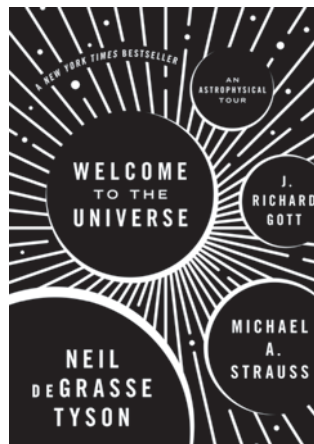
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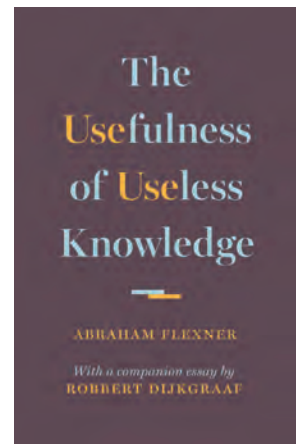
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—Sean B. Carroll,
author *The Serengeti Rules*
and *Brave Genius*

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The Unspoken



“Nature has no choice but to settle for a compromise.”

—Jim Baggott, p.46

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Trust



“To know something is one thing; but to know it with others—this is another thing altogether.”

—Simon DeDeo, p.68

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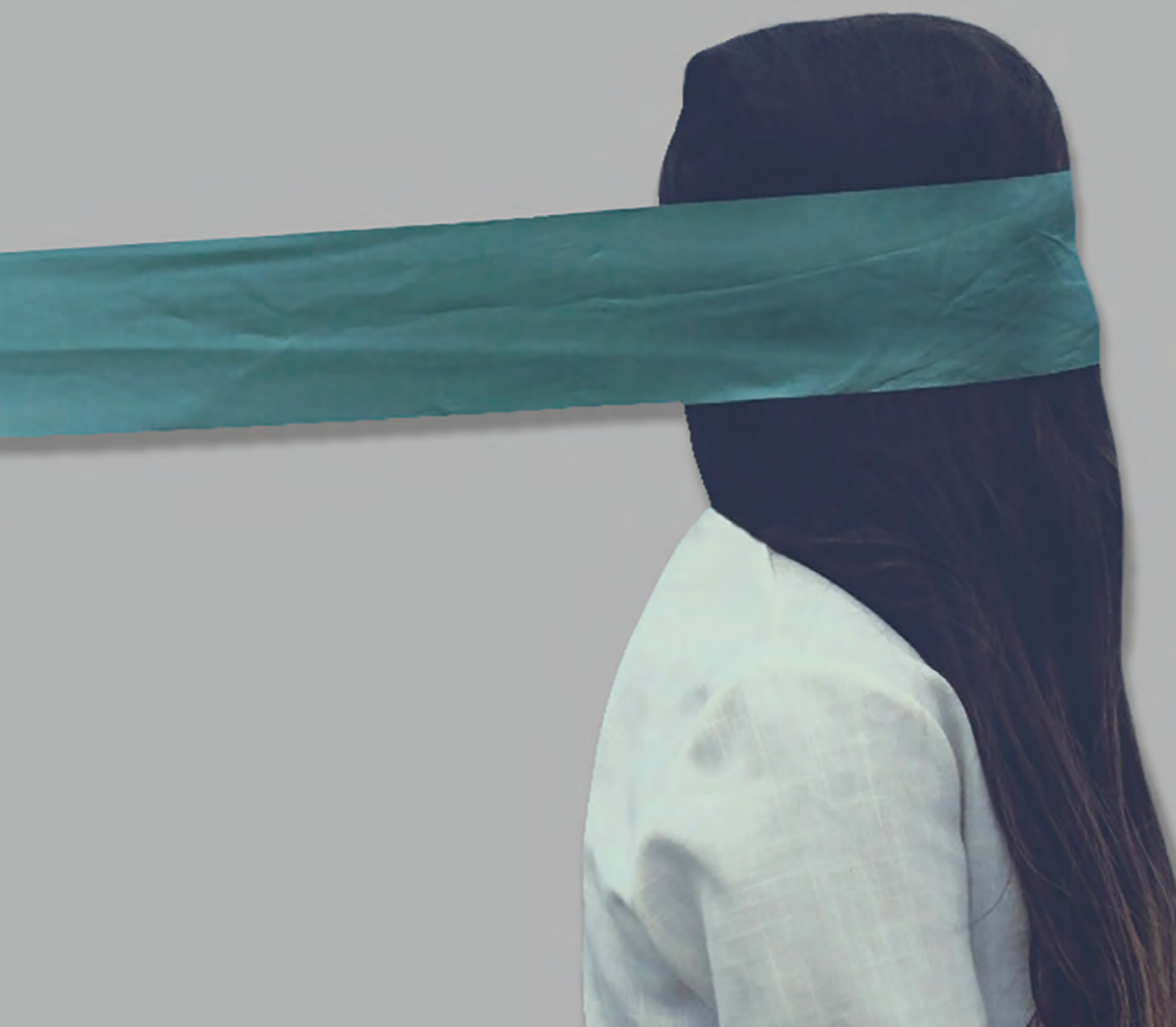
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Letters

Reader responses to the Sept/Oct 2017 print edition.

“THE LAST INVENTION OF MAN”

All this is based on the Omegas’ assumption of what is “good” for the world, but what is “good” for the world is not a fact, something you can discover or a conclusion you can reach. The scenario described is not democratic at all, it just looks like a “benevolent” dictatorship. I think most people don’t want a benevolent human dictator. Do we want a benevolent AI dictator?

—Isak

This is an interesting tale, but it tells a linear story of non-linear processes. The Roman Catholic Church knew all about the power of reading and writing for expanding the reach of its socially constructed realities, but it never saw the disruption of its empire that the invention of the printing press wrought. As tantalizing as it seems, the future of AI cannot be imagined right now.

—Doctor Tony

“GETTING GOOGLED BY YOUR DOCTOR”

Thank you for this fascinating article. As you and others reasonably ask, will this become the standard of care as more and more providers try to evaluate a sick person’s “social presence?” What dismays me is that many doctors—perhaps even most—would spend more time Googling a sick person than talking to them. What does that

betray about us? How do we discount the theatricality of social media? Do we Google everybody? And why on earth is Googling better than talking?

—David Block

“IS TRIBALISM A NATURAL MALFUNCTION?”

Even if some complex phenomena exists in a nature, it does not necessary mean that it is good. Cancer is natural, and so are parasites and appendixes. We might not fully understand the appendix, but it does not mean it is not an evolutionary rudiment.

—Alma Buru



Tampering thoughtlessly leads to trouble. On the other hand, so does refusing to do anything about a pressing problem out of concern that you might be “tampering.” It is a simple fact that



certain aspects of our psyche that were beneficial to our survival back when the most advanced weapons were sticks and stones might just be potentially *lethal* in an age of doomsday-level nuclear weapons.

—Sophia

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CONTACT

25 Broadway, 9th Floor

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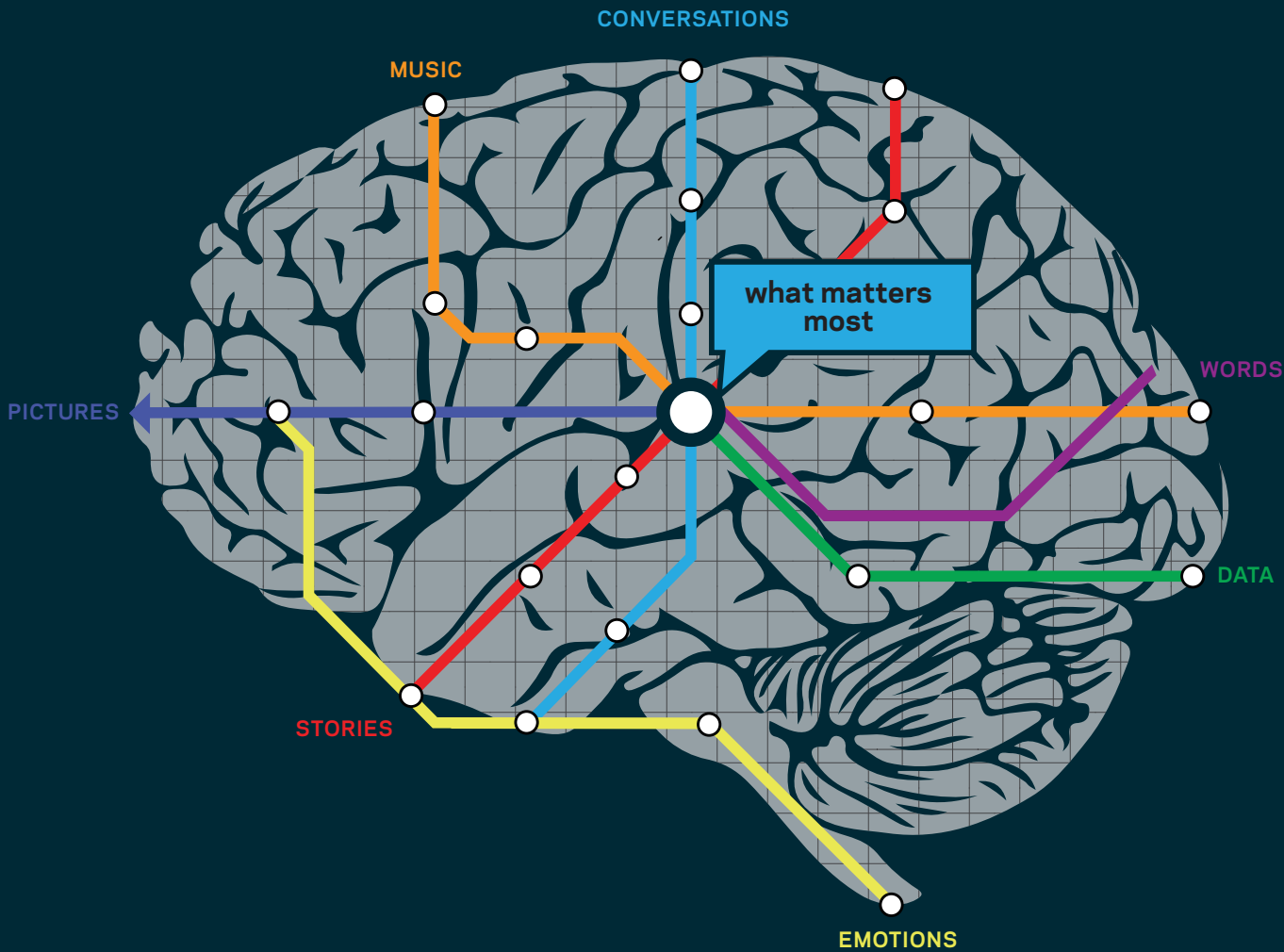
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Preludes



CLIMATE

5 Surprises Climate Change Will Throw Us

RISING SEA LEVELS, lower air quality, and longer and more frequent droughts often top the list of climate change consequences that will change our biosphere and stoke human conflict. Yet there are more startling changes to come. The interdependence of ecosystems and their inhabitants means climate change may force us to adapt in surprising ways.

There'll be more shark attacks

Warming sea temperatures have been pushing sharks north, and longer summers and warmer water mean more people on the beach. Either could lead to more reported attacks, but together they're an especially potent combination. 2015 had the highest number of reported unprovoked shark attacks globally, with 98. That's 26 more than the previous year.

People report more aggressive thoughts and behaviors when they're uncomfortably hot.

We'll have less sex

There are a lot of reasons the birth rate in the United States has been declining, from increased access to contraception to economic downturns. But it turns out climate change may be another. A 2015 paper from the National Bureau for Economic Research found that for every day hotter than 80 degrees Fahrenheit, the birth rate decreased by 0.4 percent eight to ten months later compared to the average. That may not sound like much, but it amounts to about 1,000 fewer babies born in the U.S. for each day over 80 degrees. Climate change

models predict that the number of days over 80 degrees will increase from 30 a year to 90, resulting in around 100,000 fewer births a year. The authors noted that birth rates increase on very cold days, and that this almost makes up for the dearth of births on hot days, but say there's still a net decrease.

We'll get less sleep

Based on current climate trends, by 2050 there'll be six more restless nights each month for every 100 Americans, according to Nick Obradovich, a research scientist at the MIT Media Lab, and his colleagues. By 2099, that number more than doubles to an extra 14 nights of restless sleep. Like other climate change issues, the hardest hit groups will be the poor, due to the cost of air conditioning, and the elderly, as their decreased circulation makes them more susceptible to changes in temperature. Though we still don't understand exactly how sleep works, we do know that sleep deprivation leads to decreased productivity, increased susceptibility to mental illnesses like depression, and general cognitive decline, particularly in memory consolidation. One way or another, climate change will keep you up at night.

We'll get more violent

Are you fired up? Need to let off some steam? Our heat-centered metaphors for anger might have a physiological basis. People report more aggressive thoughts, feelings, and behaviors when they're uncomfortably hot. What's more, heat doesn't just make us angrier, but also more likely to perceive

others as aggressive and confrontational. Hotter regions in the U.S. have higher rates of violent crime than cooler areas, even after controlling for factors like differences in poverty, unemployment, and age distribution. One study of almost 60 countries found that warmer temperatures were associated with violence. The authors predicted that homicide rates will increase by 6 percent for each global degree increase in Celsius.

There may be more grolar bears

Shrinking Arctic ice has forced polar bears to spend more time

on land. The warmer weather also means shorter hibernation and a more welcoming Northern climate for grizzlies. As a result, polar bears and grizzlies have been interacting much more than they used to. The resulting Grolar Bears have light brown fur, the snout of a polar bear, and the shoulders of a grizzly. They're more tolerant of warmer environments, as some of the specializations polar bears developed for retaining heat, such as fully hair-covered soles and hollow hair follicles, are not passed on fully to the hybrids.

—Victor Gomes

PSYCHOLOGY

Why Nuclear Power Professionals Are Serious About Joking Around

IN AUGUST 2013, Finland's young nuclear professionals under 35 years old met up for the Summer Games in Mikkeli municipality, put on by the Finnish Nuclear Society's Young Generation Group. As usual, the plan was to escape office life, eat, drink, use the sauna, and bond through fun competitions outdoors. The events often have a dark humor to them—they play around with nuclear disaster scenarios in ways outsiders might find jarring.

Part of what fascinates me as an anthropologist is the way nuclear experts live their lives. After living among them in Finland for almost three years, I found how they communicated in these games—using satire, jokes, and irony—surprising. In past years' games, they pretended to be emergency responders, spraying Super Soaker water guns at a beach ball they imagined to be a melting-down reactor. Their mission was to cool down its make-believe core. In another sporting event, they used a slingshot—one resembling those in

Dark humor is deeply human.

Finland's famed Angry Birds phone games—to hurl objects at a box with balloons inside. With a nuclear reactor shape painted on the box, they imagined they were terrorists attacking a power plant.

In 2013, at Mikkeli, tasks were more challenging. A large candle was placed inside a glass container, which represented a melting-down nuclear reactor and a containment building. Players, standing 16 or so feet away, had to cool it with a large water bucket and five spoons. One team devised a quirky strategy: They threw the full bucket of water at the glass, breaking it. The containment structure collapsed. The imagined reactor shut down.

I wondered how Finland's nuclear youths could treat serious threats and grave tragedies in such light-hearted, silly ways. One of the organizers explained that the Summer Games alleviated the stresses of daily work life by inverting them into their opposites. Nuclear risks were treated humorously and playfully at the yearly retreats precisely because they were treated seriously and sternly on the job every day.

A behavioral scientist might say Finland's nuclear youths used low-stakes gaming to create a “benign violation” zone, a detached distance from tragedy. This was an unserious space where meltdowns, war battles, and terrorism could momentarily seem funny. This allowed them to let off steam, kick back, and unwind together by pushing aside, temporarily, grave responsibilities they shared at work. The lightness of nuclear humor became, for them, a rejuvenating counterpoint to the

heaviness of nuclear risk.

Dark humor is key to many other high-intensity professions as well. A 2013 article explained how dark humor acts as a social “glue” reinforcing camaraderie among police officers and ambulance crews. As criminologist Sarah Charman put it, “By normalizing a situation through humor, a stressful encounter can be made more manageable—humor allows people to control feelings of fear or vulnerability.”

And yet, as anthropologist David Graeber argues, there is much more to playing than its strategic power. Play can momentarily free us from the cold demands of self-serving calculation and means-ends rationalism altogether. This holds even in serious places one might assume

to be devoid of humor. Play can be found in boring bureaucracies, among police, in austere prisons, amidst the tedium of office life, and even among nuclear engineers.

So when you hear a friend or co-worker joking about serious matters, remember to reflect on the motivations behind his or her irreverence. Dark humor is not always a callous reaction to life's tragedies. Often, it sprouts up among people who care so deeply about the day-to-day that they, every now and then, need a fun moment of release.

Finland's young nuclear professionals taught me that dark humor is deeply human—it can help one grow into a more open-minded, team-working, and enthusiastic employee.

—Vincent Ialenti

SOCIOLOGY

When It's Good to Be Antisocial

BEEES ARE EMBLEMS of social complexity. Their honeycombs house bustling hive members carrying out carefully orchestrated duties like defending against predators and coordinating resource collection. Much of our own success is due to this sort of division of labor. Clearly, in the animal kingdom, it pays to be social: There are even certain neurons that make us resent being alone. You could be forgiven for assuming that complex social organization is the—or at least a—pinnacle of evolution.

Yet out of the 20,000 known species of bees, only a few are social. Some bee species have even given up social behaviors, opting for the single life. Why?

For one, as introverts know well, socializing requires lots of energy. Highly complex societies of insects require an elaborate arsenal of chemical and



Sometimes everybody wins when you go it alone.

physical signals to direct their communal behavior. Social bees have more highly developed exocrine glands than their solitary cousins, and solitary halictid bees have less sensory hairs on their antennae than their social precursors. Solitary and social halictids also have different odorant systems, which play an important role in social bee communication and recognition. As the environment comes up with new demands, and the genetic makeup of the hive adapts, these features might just stop being worth the investment.

For another, being social can be stunting—sometimes bees have to grow up fast to survive. Researchers at Whitman College in Washington found that the region of the newly hatched antisocial orchard bee’s brain responsible for foraging ability is about as developed as the corresponding region in the experienced forager honey bee. Antisociality encourages self-sufficiency. Orchard bees must each fend for themselves, and they emerge into the world knowing how to forage for food. On the other hand, only a portion of a hive of honey bees has to forage at any given time.

How do solitary species evolve to reap these benefits after having been social? After all, antisociality cropping up, in conjunction with other stressors, can mean the collapse of the entire hive—by increasing the minimum amount of social bees needed to sustain a hive, and decreasing the maximum amount of bees a hive can stably carry. So the prevalence of loners is not exactly favorable.

Variability in social behavior is

one possible answer. *H. rubicundus*, a sweat bee descended from social ancestors in the Halictidae family, has both solitary and social populations in Europe. Bees living in different environments prefer different behaviors: In warm climates, *H. rubicundus* populations favor hive-formation, while in the cold, they tend to go solo.

It also turns out that, even in a highly coordinated hive, antisocial individuals persist. And they appear to be tolerated by other bees in the colony. If a few loners find themselves in a new situation where solitary behavior is advantageous—say the growing season is short and bees need to get up and go without dividing tasks—an asocial species could arise.

Changes in host plants can also lead social bees to revert to solitary behavior. Specializing on one plant is usually more beneficial in a hive, where the activity of the hive can be coordinated around a constant resource. But solitary bees are usually generalists—they buzz along from one plant species to another.

Sociality is no pinnacle of evolution. It’s just another result of the process. Reclusive bees and other species are doing just fine—and sometimes, even better. Clearly social behavior has advantages, seeding the survival of species and communities. But being a good neighbor is not the only benefit to the hive. Sometimes everybody wins when you go it alone.

—Silvia Golumbeanu

ONE QUESTION



Nate Soares

Why is rogue AI a real worry?

Executive Director of the nonprofit Machine Intelligence Research Institute

Laypeople often imagine the *Terminator* movies, but I think the “Sorcerer’s Apprentice” short from *Fantasia* is a much better illustration of artificial intelligence going wrong. The problem Mickey faces when he enchants a broom to help him fill a cauldron isn’t that the broom “rebels” or “acquires a will of its own,” but that it fulfills the task it was given all too well. Mickey specified that he wanted the bucket full, and overflowing the workshop is a great way to be extra confident that the bucket is full (and stays full). But Mickey’s actual goals were much more complicated than just “fill the bucket.” Mickey successfully “aimed” his “AI system,” and the broom filled the stated objective (as best it could, using lots of creative thinking), but things still went poorly for Mickey. This isn’t a problem with AI systems working in narrow domains today, but as they get cleverer, and as they work in more complicated situations, it gets harder to find directions we could aim them in with good results.

LOGIC

A Riddle in a Graveyard

YOU'VE BEEN CAUGHT snooping around a spooky graveyard with your best friend. The caretaker, a bored old man fond of riddles, imprisons each of you in a different room inside a shed, and, taking your phones, says, "Only your mind can set you free." Through a window, you can see 12 statues. Out of your friend's window, which overlooks the opposite side of the graveyard, she can see eight. Neither of you know the other's count.

The caretaker tells you each, individually, that together you can see either 18 or 20 statues. Unfortunately, there's no way to tell your friend how many you see. The only way for you both to escape is for one of you to give the total number of visible statues. Get it wrong, and neither of you ever leave. The caretaker asks you each one at a time, once a day, and you can choose to answer or to pass. You and your friend both know that you're always asked first. If you both pass on a given day, the question—are there 18 or 20?—is posed to each of you again the next day, and the next, and so on, until you get it right or wrong.

First, you and your friend have to realize that each "pass" counts as a signal. Given that you haven't had time to consult with each other before being separated, this will require some intelligence—and confidence in each other. In game theoretic terms, this establishes the needed "common knowledge" to escape.

Day 1

If you saw 19 or 20 statues, then you could conclude there are 20. But you only see 12, so you pass. This signals to your friend that you see at most 18 statues.

If your friend saw zero or one statues, knowing that you see at most 18, she could conclude there would have to be 18. But your friend sees eight, so passes. This signals to you that she sees at least two statues.

Day 2

If you saw 17 or 18 statues, then you could conclude there are 20 because your friend must see at least two.



Use your common knowledge to escape.

But you only see 12, so you pass. This signals to your friend that you see at most 16 statues.

Now if your friend saw two or three statues, knowing that you see at most 16, she could conclude there would have to be 18 statues. But your friend sees eight, so she has to pass. This signals to you that she sees at least four statues.

Day 3

If you saw 15 or 16 statues, then you could conclude there are 20 because your friend must see at least four. But you only see 12, so you pass. This signals to your friend that you see at most 14 statues.

Now if your friend saw four or five statues, knowing that you see at most 14, she could conclude there would have to be 18. But she sees eight, so she has to pass again. This signals to you that your friend sees at least six statues.

Day 4

If you saw 13 or 14 statues, then you could conclude there are 20 because your friend must see at least six. But you only see 12, so you pass. This signals to your friend that you see at most 12 statues.

Now if your friend saw six or seven statues, knowing that you see at most 12, she could conclude there would have to be 18. But your friend sees eight, so she has to pass again. This signals to you that she sees at least eight statues.

Day 5

Since your friend sees at least eight statues, and you see 12, you know there are 20. You're free!

—Brian Gallagher



PHOTOCOLLAGE BY **FRANCESCO IZZO**



The Rise and Fall of the English Sentence

The surprising forces influencing the complexity of the language we speak and write

BY JULIE SEDIVY

“[[[When in the course of human events it becomes necessary for one people [to dissolve the political bands [which have connected them with another]] and [to assume among the powers of the earth, the separate and equal station [to which the Laws of Nature and of Nature’s God entitle them]]], a decent respect to the opinions of mankind requires [that they should declare the causes [which impel them to the separation]]].”

—Declaration of Independence

A **N ICONIC SENTENCE, THIS.** But how did it ever make its way into the world? At 71 words, it is composed of eight separate clauses, each anchored by its own verb and indicated here with square brackets, nested within one another in various arrangements. The main clause (*a decent respect to the opinions of mankind requires ...*) hangs suspended above a 50-word subordinate clause that must first be unfurled. Like an intricate equation, the sentence exudes a mathematical sophistication, turning its face toward infinitude.

To some linguists, Noam Chomsky among them, sentences like these illustrate an essential property of human language. These scientists have argued that recursion, a technique that allows chunks of language such as sentences to be embedded inside each other (with no hard limit on the number of nestings) is a universal human ability, perhaps even *the* one uniquely human ability that supports language. It’s what allows us to create—literally—an infinite variety of novel sentences out of a limited inventory of words.

But that leads to a curious puzzle: Complex sentences are not ubiquitous among the world’s languages. Many languages have little use for them. They prefer to string together simple clauses. They may even lack

ILLUSTRATIONS BY FRANCESCO IZZO

certain words such as relative pronouns *that* and *which* or connectors like *if*, *despite*, and *although*—these words make it possible to link clauses together into larger sentences. Allegedly, the Pirahã language along the Maici River of Brazil lacks recursion altogether. According to linguist Dan Everett, Pirahã speakers avoid linguistic nesting of all kinds, even in structures such as *John's brother's house*. (Instead, they would say something like: *Brother's house. John has a brother. It is the same one.*)

This can't be pinned on biological evolution. All evidence suggests that humans around the world are born with more or less the same brains. Abundant childhood exposure to a language with layered sentences practically guarantees their mastery. Even adult Pirahã speakers, who have remained unusually isolated from European languages, pick up the trick of complex syntax, provided that they spend enough time interacting with speakers of Brazilian Portuguese, a language that offers an adequate diet of embedded structures.

More useful is the notion of *linguistic* evolution. It's the languages themselves, rather than the brains, that have evolved along different paths. And just as different species are shaped by adaptations to specific ecological niches, certain linguistic features—like sentence complexity—survive and thrive under some circumstances, whereas other features take hold and spread within very different niches.

Languages with very simple sentence structure are, for the most part, oral languages. It's the languages that have a culture of writing, developed over a long span of time, that display a fondness for stacking clauses onto one another to create towering sentences. This pattern raises the possibility that the invention of writing, a very recent innovation tagged on to the very last millennia of human evolution, can dramatically alter a language's linguistic niche, spurring the development of elaborate sentence structure, and leading to the shedding of other features, on a timescale that cannot be achieved through biological evolution. If that's so, then the languages that many of us have grown up with are very different from the languages that have been spoken throughout the vast majority of human existence.

MANY OF THE WORLD'S ORAL LANGUAGES are quite unlike European languages. Their sentences contain few words. They rarely combine more than one clause. Linguist Marianne Mithun has noted some striking differences: In English, 34 percent of clauses in conversational American English are embedded clauses. In Mohawk (spoken in Quebec), only 7 percent are. Gunwinggu (an Australian language) has 6 percent and Kathlamet (formerly spoken in Washington state) has only 2 percent. An English speaker might say: *Would you teach me to make bread?* But a Mohawk speaker would break this down into several short sentences, saying something like this: *It will be possible? You will teach me. I will make bread.* In English, you might say: *He came near boys who were throwing spears at something.* A Kathlamet approximation would go like this: *He came near those boys. They were throwing spears at something then.*

Some oral languages do regularly embed clauses, suggesting that writing is not *necessary* for complex syntax. But, as can be seen in a number of indigenous languages, longer and more complicated sentences often emerge as a result of contact with a written language. Structurally useful words (*if, and then, because, but*) have spread from Spanish to various Mexican languages such as Nahuatl, Sierra Popoluca, and Otomi, with the latter borrowing heavily from Spanish; in one sample, almost 80 percent of Otomi subordinate clauses began with borrowed connector words. (Only four such words are native to Otomi; in contrast, Spanish has 40.) Moreover, languages may borrow the concept of certain relationships between clauses, but not the exact words. This can be seen in various Iroquoian languages which have a word for “*and*” that doesn’t derive from a common linguistic ancestor, but instead reflects recent adaptations of each language’s own linguistic resources to express the notion of and-ness.

The development of intricate sentences in modern European languages has unfolded slowly. These languages now churn out relative clauses with boundless enthusiasm but their common ancestor, Proto-Indo-European, may have lacked the necessary grammatical tools to produce them at all. According to linguist Guy Deutscher, the earliest clay tablets (about 2500 B.C.) of the ancient language Akkadian reveal few embedded clauses. The same is evidently true of the earliest stages of other ancient written languages such as Sumerian, Hittite, or Greek. Although these languages boasted a profusion of grammatical features suitable for expressing subtle

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nuances of meaning, and included a variety of fancy word-building techniques, they avoided complicated sentence recursion. When they did combine clauses into larger structures, this technique looked less like Russian dolls, with one clause inside another, and more like beads on a necklace, with one clause added next to another, and resembled this sentence from an old Hittite text (14th century B.C.):

I drove in a chariot to Kunnu, and a thunderstorm came, then the Storm-God kept thundering terribly, and I feared, and the speech in my mouth became small, and the speech came up a little bit, and I forgot this matter completely, but afterwards the years came and went, and this matter came to appear repeatedly in my dreams, and God's hand seized me in my dreams, and then, my mouth went sideways, and ...

The invention of writing sparked certain innovations such that by 1800 B.C., Akkadian texts already exhibited complex sentences that rival the prose of Henry James in their complexity. One such sentence (from Hammurabi's Code of Law) proceeds like this:

[If, [after the sheep and goats come up from the common irrigated area [when the pennants announcing the termination of pasturing are wound around the main city gate], the shepherd releases the sheep and goats into a field], the shepherd shall guard the field].

The divergence between spoken and written language can be witnessed around the world, at all time scales. Compare, for example, the number of Finnish subordinate clauses in the old oral tradition to modern written Finnish. There *are* embedded clauses in *The Kalevala* (a collection of folk poetry that constitutes the Finnish national epic). But there are not very many: a 1,300-word sample yields three fairly simple examples, but a 1,300-word stretch of current written Finnish would typically contain about 60—and these would be more varied and more complex. A more recent example: The Somali language had essentially no written tradition until 1972, when it became the official state language. Over a mere 20-year period, researchers have observed noticeable changes to the written language, such as the emergence of longer and more complex words and greater elaboration of sentence structure.

Modern languages with a long literary tradition show a stark split between their written and spoken styles. In current English, writing uses more varied vocabulary than conversational speech, and it uses rarer and longer words much more often. Certain structures (such as passive sentences, prepositional phrases, and relative clauses) appear more often in written than spoken language. Writers generally elaborate their ideas more explicitly through syntax whereas speakers leave more material implicit. And written language stacks clauses inside each other to a greater depth than spoken language. This is one of the most striking differences between speech and text; sentences like the opening line of the Declaration of Independence simply do not occur in conversation.



WHY AND HOW did syntax explode like this? For one thing, writing creates an entirely different communicative environment from spoken interactions, with text intensifying certain pressures and relaxing others. When writing is first introduced into a society, it is typically used mainly as a record of spoken language, but as writers eventually write for *readers*, not *hearers*, the language of text diverges from speech. Some existing features come to be used more generously than in spoken language, and new grammatical tools may be introduced.

Speech also proceeds under the whips of two tyrants: time and memory. Our memories aren't nearly capacious enough to allow us to compose and precompile each sentence before beginning to utter its first syllable. Instead, speaking is like driving with a general sense of the destination, but no clear route planned—we utter the first syllables of a sentence while taking a leap of faith that we'll be able to choose the right words en route and

formulate phrases adequately as the words tumble out of our mouths and bring us to an intersection in our thoughts that demands our next move. This puts an upper bound on complexity. But written text, which can be more deliberately planned out and revised, is able to transcend this.

Readers too, and not just writers, are sprung from the shackles of time and memory. If reading were like hearing language, we would view text through a two-character aperture moving inexorably forward, unable to slow down, pause, or dart back and re-read. But eye-tracking studies show that when we read, we break free of linear time and seize control over the flow of information, our eye movements lurching along at inconsistent speeds and frequently jumping back to earlier parts of a sentence which, during speech, would already be auditory vapor. Such freedoms invite the most glorious excesses of recursion in text.

The complex syntax fostered by writing seems to be an acquired skill much like mental arithmetic. More or less everyone is born with the potential to do it, but to be able to calculate truly spectacular equations in your head, you need heavy practice, just as to understand (and compose) elaborate sentences with ease, you need plenty of experience with such sentences. Reading transforms the experiential landscape, offering a range and complexity of sentence structure that is rarely found in speech.

When children are fed a steady linguistic diet that is rich in complex sentences, these become easier to compute, and in turn, more readily produced under the time pressures imposed by speech. For example,

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psychologist Jessica Montag and her colleagues targeted relative clauses in the passive voice (*the dog that was hit by the car*), which are exceedingly rare in speech but more abundant in text, even that written for children. They found that heavy readers in the 8- to 12-year-old range produced such structures more often than children who read less. Even among adults, the production of these sentences was highly correlated with how much text they consumed, suggesting that avid readers are far more likely to transmit complex sentences to future generations.

All of this suggests that exposure to literary language is essential for the health of complex recursive sentences in English. If certain structures are too rare in speech to be reliably mastered by learners and passed on, then they may fade out within a community of non-readers. Naturally, this raises the question: Could syntactic complexity in literate languages diminish over time, if new technologies (podcasts, video lectures, and audiobooks) tether language more tightly to speech and its inherent limitations?

In fact, heavily recursive sentences like those found in the Declaration of Independence have already been dwindling in written English (as well as in German) for some time. According to texts analyzed by Brock Haussamen, the average sentence length in written English has shrunk since the 17th century from between 40-70 words to a more modest 20, with a significant paring down of the number of subordinate and relative clauses, passive sentences, explicit connectors between clauses, and off-the-beaten-path sentence structures.

These changes may reflect shifts in readers' experience with language: Where literacy used to be an elite skill commanded by a very few steeped in lives of scholarly study, now it's a universal basic necessity. More people now read—because they have to—but many probably still consume the vast bulk of their linguistic diet in spoken form and may have little patience for writing that is mentally taxing and reeks of snobbery. The need to make text accessible to a broader population, with a wide range of linguistic experiences, has created some pressure to bring the structures of written English more in line with spoken English.

Still, the English language represents not a single ecosystem, but many. A bird's-eye view of the overall trajectory of English would miss some of the most dramatic changes occurring within its particular linguistic niches. That brings to the fore another key reason why language might gravitate toward streamlined syntax: the nature of the communities that use it.

ORAL LANGUAGES MAY AVOID pushing the limits of syntax not just because they are bound to speech, but also because they have other ways to express complex meanings. Linguists take great pains to point out that languages with simple sentences erupt with complexity elsewhere: They typically pack many particles of meaning into a single word. For example, the Mohawk word *sahonwanhotónkwahse* conveys as much meaning as the English sentence “She opened the door for him again.” In English, you need two clauses (one embedded inside the other) to say “He says she’s



leaving,” but in Yup’ik, a language spoken in Alaska, you can use a single word, “*Ayagnia*.” (*Ayagniuq*, in contrast, means “He says he himself is leaving”; *Ayagtuq* means, more simply, “He’s leaving.”)

The templates for creating such complex words can be unruly, making them seem, to the average English speaker, more like cryptographic problems than words. Linguist John McWhorter offers an astounding example from the Siberian tongue Ket, a language in which verbs take pronoun prefixes to mark who is performing an action. There are two different sets of prefixes that attach to different verbs, and you simply have to *know* which verb takes which set. Moreover, many verbs simultaneously take two pronoun prefixes that mean the same thing (but many don’t—you just have to *know*), which trigger subtle shifts in meaning. For instance, *digdabatsaq* means “I go to the river and come back a bit later,” but *digdaddaq* (which involves the double use of the same pronoun prefix *d*) means “I go to the river and stay for a season.” The same word with just

one pronoun—*digdaksak*—means “I go to the river and stay some days or weeks.”

If such a language seems unlearnable, well, that is exactly the argument that linguists such as McWhorter have been making: that an adult venturing into Ket would inevitably mangle it, just as an adult learner of English may never quite grasp its irregular verbs or idiosyncratic prepositions (why do you say *in a club* but *on a team*?). The unpredictable aspects of language, the things you just have to know, may be especially slippery for the adult mind—and there are so many more of these in Ket than in English. This could be why languages that rely on dense words in all their irregular glory tend to be *esoteric*—that is, spoken within small and insular communities, where everyone who speaks the language has been marinating in it since birth. The inscrutability of such languages may have the effect of repelling outsiders, ultimately reinforcing their insularity.

Complex and quirky words tend to be pruned out by *exoteric* languages, which are spoken in more porous communities that include a diversity of learners of all ages. Instead, exoteric languages rely on systematic rules that, like rules of arithmetic, offer tidy procedures for creating complex meanings (elaborate sentences) out of easily-mastered elements (simple words). Once learned, these procedures can be applied to any new combination of words. In contrast, the intricate words of many esoteric—and typically oral—languages are amalgams of meanings that have likely become fused together in the minds of speakers over countless instances of use. In other words, where speakers of English or German have become adept at performing the linguistic equivalent of mental arithmetic, speakers of Ket or Yup'ik don't have to: They have mastered a mind-boggling number of “math facts.”

The insularity of many oral languages also reduces the need for syntactic elaboration in a more direct way: Speakers within a small, tight-knit community have an immense store of shared knowledge. This allows shortcuts in communicating with each other, so that many aspects of meaning can be left implicit. But these shortcuts are not available to speakers of big, sprawling languages who communicate with each other across divides of culture, experience, and specialized knowledge. And writing stretches the distance between participants even wider, allowing writers to communicate with unseen readers across expanses of time and space, thus amplifying the pressures that drive exoteric languages to syntactic complexity.

The borders that enclose some of the world's smallest and most intimate language communities give us another handle on understanding the waning of sentence complexity in English. Linguists Douglas Biber and Bethany Gray have documented some specific shifts away from syntactic elaboration beginning in the 20th century—but these are not taking place in the language's most democratic public squares. Instead, they have been fomenting within one of its most esoteric corners, that of specialized scientific writing. And far from representing an impulse to embrace

a diversity of readers, they reveal increasingly insular communities—communities that can dispense with detailed embedded clauses simply because they do not *have* to make meanings explicit to readers who share troves of background knowledge.

Over the course of the 20th century, scientific communities began to splinter apart into highly specialized sub-disciplines. This coincided with a new tendency for academic prose to compress elaborate sentence structure into tighter, smaller expressions—for example, “actions that the government initiated” might become the compound noun “government actions.” What’s striking about such compound nouns is that they are like math facts: They rely on *memorized* rather than *computed* meanings. A *house boat*, for example, is a *boat that functions like a house*, but a *housecoat* is a *coat you wear in a house*, and a *housewife* fits neither pattern. There is no general algorithm that yields a predictable meaning for a compound. A reasonable guess is often possible but sometimes, you just have to *know*.

Biber and Gray note that noun compounds increased by more than 400 percent over the 20th century, and there was an explosion in the types of nouns that could be merged. As a result, even when they join everyday nouns, the precise meaning of compounds may be opaque without specialized knowledge: a *storm surge* is a surge in the level of water due to a storm; *harvest effect* refers to the extent to which the magnitude of a harvest varies. During the second half of the 20th century, three- and four-noun

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combinations proliferated, and now we have noun pile extravaganzas such as *state hate crime victim numbers*. A 19th-century writer might have written instead: *the numbers of victims who have experienced crimes that were motivated by hatred directed at their ethnic or racial identity, and who have reported these crimes to the state*.

These new complex, compressed, meaning-particle-mashing noun compounds bear more resemblance to the intricate words of Ket or Mohawk than to the airy periodic sentences of the Declaration of Independence. This is likely no accident. Biber and Gray point out that scientific prose, which used to be written for any reasonably educated person, has come to target smaller and smaller communities of close colleagues—like the small, close-knit communities that have nurtured many of the world’s oral languages and their meaning-dense linguistic units.

Evidence shows that the most insular scientific communities have led the march away from elaborated sentences in favor of complex, compressed nouns: Science articles in specialist publications such as the *Journal of Cell Biology* contain fewer relative clauses and more noun compounds than articles in publications like *Science*, which target a more diverse community of scientists. Both of these samples in turn have less syntactic elaboration and more compression than academic writing in the humanities, which presupposes even less specialized knowledge among its readers. And lagging behind all of these in the trend toward noun-heavy compression is the language of novels and plays. And, as Biber and Gray have shown, university students learn the art of compression gradually, with those in the sciences coming to rely less on multiple clauses and more on complex nouns than their peers in the arts and humanities.

These findings highlight the extent to which languages are shaped by the structure of their communities—so much so that even a cosmopolitan globe-straddling language like English contains within it an esoteric register whose linguistic opacity has the effect of repelling outsiders and reinforcing the insularity of its community. ☺

JULIE SEDIVY has taught linguistics and psychology at Brown University and the University of Calgary, and is the author of *Language in Mind: An Introduction to Psycholinguistics*. She is currently writing a book about losing and reclaiming a native tongue.

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THE PHILOSOPHERS KNEW IT FIRST. “Silence is the element in which great things fashion themselves together,” wrote Thomas Carlyle in 1831. Since then, science has redefined the word. When we rest, our brain’s default mode network lights up. Exposure to the broken and absurd primes our learning faculties. Voiceless animals show rich, culture-like behavior.

Speech turns out to be the tip of an iceberg, and some of our most dearly held beliefs submerged. In a world filling with expression, will we end up missing its absence?

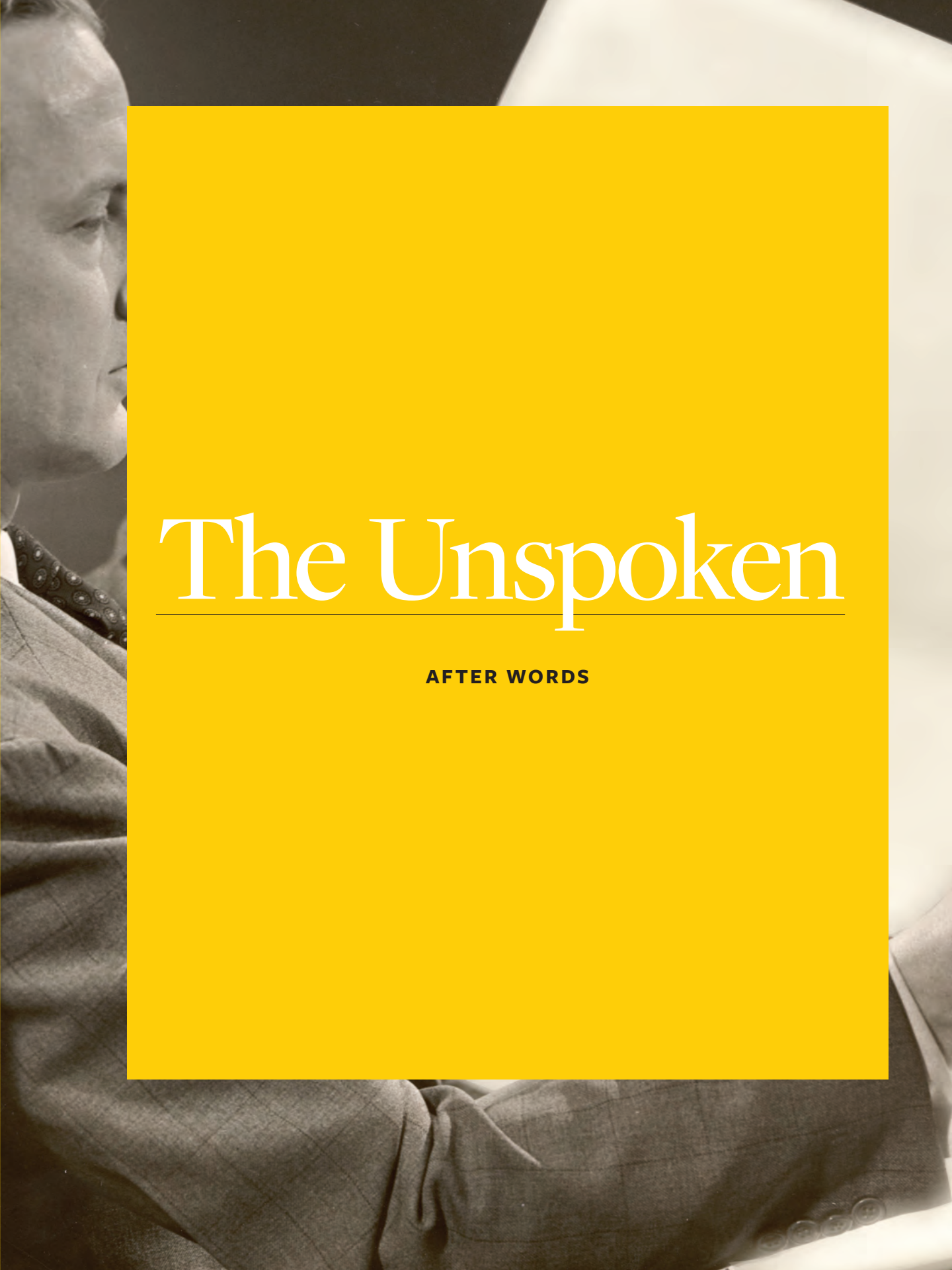
Welcome to “The Unspoken.”

—MS

“Why *don’t* we allow children access to the world as we know it, a world that involves death and sex and, yes, sometimes even machetes?”

DORSA AMIR

“Love, Death, and Other Forgotten Traditions” p.34



The Unspoken

AFTER WORDS



Love, Death, and Other Forgotten Traditions

What we don't tell our children

BY DORSA AMIR

THE SCIENCE-FICTION WRITER Robert Heinlein once wrote, “Each generation thinks it invented sex.” He was presumably referring to the pride each generation takes in defining its own sexual practices and ethics. But his comment hit the mark in another sense: Every generation has to reinvent sex because the previous generation did a lousy job of teaching it.

In the United States, the conversations we have with our children about sex are often awkward, limited, and brimming with euphemism. At school, if kids are lucky enough to live in a state that allows it, they’ll get something like 10 total hours of sex education.¹ If they’re less lucky, they’ll instead experience the curious phenomenon of abstinence-only education, in which the goal is to avoid transmitting any information at all. In addition to being counterproductive—potentially leading to *higher* rates of teen pregnancy² and sexually transmitted illnesses³—this practice is strange. Compare it to the practices of many small-scale societies,

where children first learn about sex by observing their parents!

One of the most distinctive features of the human species is its practice of cultural transmission. Our ability to retain, refine, and pass down cultural knowledge across generations has helped us survive in every habitat on the planet—and even in space. Just 350 generations ago, we were making the switch from foraging to early agriculture. Now, the sum of human cultural knowledge, passed from parent to child for thousands of years, is a Google search away.

So why is it that, despite having immediate access to virtually every area of knowledge, we Westerners paradoxically fail to directly share the most important of these insights with the next generation? Sometimes intentionally under the banner of protecting young minds, sometimes unintentionally as a result of the way our communities are structured, we dam critical information and force new generations to start from scratch, leaning on their own intuitions and the scant



CHILD'S PLAY A child mowing grass with a knife is an ordinary scene in Shuar communities.

experience of their peers to chart a way forward. From birth and parenting to death and burial, we have built a knowledge dam that makes it harder to lead successful lives.

It doesn't have to be this way—and, in fact, it wasn't, until very recently.

WE ARRIVED SHORTLY BEFORE SUNSET, after a three-hour canoe ride down a winding river in the Amazon. This was the main way to reach the Shuar community of La Libertad. To welcome us, the elected leader invited us to dine with his family, offering to serve one of his hens. At this suggestion, his wife nodded, picked up a sharpened machete, and recruited the help of her young daughter, who looked to be no more than 8 years old. Together, mother and daughter grabbed the unlucky bird and proceeded to slaughter it with a swift machete strike to the neck. The act itself

was less surprising than the casualness with which it was done; neither batted an eye at what was, at the time, the first animal I'd seen slaughtered.

Throughout my years of fieldwork with the Shuar, I've witnessed a catalog of behaviors that would shock Western* parents. I've imagined how they would stare in alarm at the sight of children setting fire to fields, walking barefoot past tarantulas, or mowing grass with knives. But as the years have gone on, I've found myself less surprised by the culture of the Shuar, and more surprised by our own. Why *don't* we allow children access to the world as we know it, a world that involves death and sex and, yes, sometimes even machetes? After all, there's good reason to think that small-scale societies like the Shuar, though not perfect mirrors into the past, are living in ways that closely resemble the lifestyles of our predecessors. Maybe they've held onto something we've recently lost.

* I'll be using "Western" as a shorthand for societies that are best known as WEIRD societies: Western, Educated, Industrialized, Rich, and Democratic.

Every generation has to reinvent sex because the previous generation did a lousy job of teaching it.

One of the more defining features of small-scale societies is the structure of their communities. While Westerners live in nuclear families with low birth rates, those in small-scale societies tend to have more children and live in extended networks of nearby kin. For instance, many Shuar now live in *centros*, or centralized communities. Homes are often built around community centers or open fields, with clusters of families, commonly linked through a patriarch, living next door to each other. Many homes are still built in the traditional style, with bamboo walls and thatched roofs, inside which everyone shares one big room. This makes privacy a scarce resource and also means that much of life takes place in full view of the next generation (and sometimes in front of the odd anthropologist).

Another unique aspect of small-scale societies like the Shuar is that they are frequently natural fertility populations, meaning there's little or no systematic use of birth control (some plant-based birth control does exist). As you can imagine, one consequence of this is that there are lots of babies, and they're everywhere. From an early age, most people—particularly young girls—are tasked with caring for their siblings,

so by the time they are having their own children, they already have years of experience. This experience can prove useful because babies are confusing, especially at first. Countless new fathers have begun their lifelong foray into dad jokes by quipping about the need for some sort of user's manual—a need an enterprising doctor and his son have recently responded to.⁴ But the very fact that Westerners often look to things like books to discover what babies actually *are* is a strange phenomenon in itself.

One reason for this confusion is that we don't live like the Shuar or our ancestral predecessors, in large networks of nearby family. Instead, our communities are structured around the nuclear family, with other kin largely absent, unable to offer guidance. That, coupled with the social and economic challenges of our labor system, make it difficult for knowledge to make it through the generational pipeline. And in some countries, such as the U.S., previous generations may have already lost some of their baby-specific knowledge. For example, in the recent past, mothers relied much more heavily on formula feeding: 3 out of 4 of babies in America were bottle-fed in the 1970s.⁵ This means

firsthand knowledge of successful breastfeeding may have been temporarily lost within families, and had to be rediscovered by more recent generations. Perhaps this is a contributing factor to why only a third of American mothers make it through the first six months of nursing.

Compare the experience of American mothers to those of the Himba, an ethnic group in Namibia who largely survive by herding livestock. Virtually all Himba mothers breastfeed, and they make it look easy; women can be spotted multi-tasking—walking, chatting, eating—all while they feed their infants. But work by Brooke Scelza, an anthropologist at the University of California, Los Angeles, has revealed that Himba mothers initially struggle with breastfeeding at about the same rates as American parents.⁶ So how do they persevere? Brooke argues that it's all about grandmothers: Himba mothers move in with their own mothers in the last stretch of their pregnancy and stay put throughout the first few months. This means they have consistent access to both direct care and, importantly, cultural information about early childcare. The importance of generational knowledge in early parenting is evident across an ecologically and geographically diverse range of other small-scale societies, such as the Martu of Australia,⁷ the Hadza of Tanzania,⁸ and the Efe of the Democratic Republic of the Congo.⁹ We see a similar pattern among the Shuar. The birth and care of a new infant is a family affair, with grandparents and siblings frequently present to help by sharing what they know.¹⁰ This cultural transmission from previous generations,

in fact, is arguably one of the reasons why grandmothers are so important.

Another generational lapse in our cultural knowledge of parenting may have happened with sleep. Look at virtually any small-scale society in the world and you'll see the same thing: Mothers sleep side-by-side with their infants, ready to nurse at a moment's notice. Even the composition of human breast milk suggests this mode of feeding is more natural. It is relatively low in fat compared to other mammals, meaning that humans are demand feeders—our babies nurse when they need to, even through the night. This is a world away from the average American parent, sleeping in a separate room from his or her infant, anxious as to whether their child will sleep. As psychologist Cristine Legare discovered on the island of Tanna, non-Western parents don't just think this practice is strange, they think it's concerning. "How can mothers tell if their babies are safe if they're sleeping in another room?" they would ask her in astonishment. Both of those practices—the separation of infant from parent and the expectation of a full night's sleep—are out of step with what takes place in communities like those of Melanesians and the Shuar.

How did we end up with these norms? Like the case of breastfeeding, there's reason to think there was a generational loss of information. Up until the 19th century, co-sleeping was widely practiced, even in the U.S. Industrialization, the medicalization of infancy, and the fear of coddling children changed our norms. Today, co-sleeping is being slowly reintroduced into

We Westerners go out of our way to avoid thinking about death.



IT TAKES A VILLAGE In Shuar communities, raising children is a group effort.

our culture, but essentially without firsthand knowledge of how to do it.

AT THE OTHER END of the human experience is death. Among small-scale societies, funerary practices often involve whole communities. The Torajans of Indonesia have been known to delay burial for months or years, and engage in a ritual called the Ma'Nene, in which they proudly display the bodies of their family members, washing, grooming, dressing, and walking them around their villages. The Wari' of western Brazil not only directly interact with the corpses of their loved ones, but ritually ingest their bodies as a way of honoring them. Funerary practices among the Shuar included laying out the deceased in hollowed-out logs and placing them in small houses, in which food offerings were made for two years. This practice has largely disappeared, as many Shuar now bury their dead in communal cemeteries, often near missions. However,

unlike in the West, there is no specialized trade for mortuary practices; the family and the community must perform the burial themselves.

Though these practices may seem foreign to Westerners, variations of these themes exist in our cultures as well. The best-known may be the Day of the Dead celebration in Mexico, a multi-day holiday where families adorn the graves of their loved ones with altars of marigolds, even bringing toys for dead children. These are lively community gatherings filled with food, music, and costumes. Importantly, children are encouraged to participate in these traditions, a process that psychologist Karl Rosengren has described as an important part of their socialization.

Despite being virtually the only assured experience in life, we Westerners go out of our way to avoid thinking about death entirely. We look away from it, outsourcing funerary processes to others, and even avoiding using the word, opting for euphemisms like



PLAYING WITH FIRE Shuar children use fire to control growth in a field.

deceased, departed, or passed away. We also take extra care to keep our children ignorant of it under the guise of protection, again preventing information from being transferred from one generation to the next. Our lack of vocabulary and experiential priming can make it hard to deal with death when we inevitably encounter it.

It wasn't always like this. Just as breastfeeding was once more prevalent in our culture prior to the 1970s, there was a time when death was welcome in our living rooms. In the Victorian era, the funeral parlor was the parlor of your home; the body of loved ones would often rest on an ice board, and embalming might take place in the kitchen. Friends and families would gather together to have tea, to chat, all the while saying goodbye to the body on display. It's likely that this practice helped the bereaved deal with the reality of death.¹¹

I OFTEN FIND MYSELF THINKING BACK to a classic adage about the role of anthropology; our task, it's

been argued, is to “make the strange familiar and the familiar strange.” When I first visited the Shuar, I kept noticing the ways in which their lives were strange to me. I'd never lived in a world where privacy was scarce, where children were independent and free to structure their own time, where family was just a holler away, and parents didn't sugarcoat the realities of birth and sex and death. But as time has gone on, one of the oddest parts of fieldwork now is returning home. I see our societies in a different light, acutely aware of how unaware we are of the strangeness of our own culture and the ways in which it's transmitted. In the case of parenting, the breakdown of information transmission between generations was probably unintentional. After all, how many parents and grandparents have the resources to live together? But there's something else going on with sex and death. In those cases, there is an intentional sequestering of information, an attempt to leave the innocence of youth unspoiled. This is the

Knowledge Dam, the stoppering of cultural transmission to the next generation, and it's a mistake. The next generation of humans *will* encounter death. They'll have sex, and drink alcohol. They'll have children, and raise them, and their children will all eventually die, too. The less we share our understanding of the world, the less prepared our children are to understand it. Cultural transmission has scaffolded the human experience for millennia. Why stop now? ☹️

DORSA AMIR is a Ph.D. candidate in biological anthropology at Yale University.

REFERENCES

1. US Department of Health and Human Services, Centers for Disease Control and Prevention "Results from the School Health Policies and Practices Study 2014" (2015).
2. Stanger-Hall, K.F. & Hall, D.W. Abstinence-only education and teen pregnancy rates: Why we need comprehensive sex education in the US. *PLoS One* **6**, e24658 (2011).
3. Hogben, M., Chesson, H., & Aral, S.O. Sexuality education policies and sexually transmitted disease rates in the United States of America. *International Journal of STD & AIDS* **21**, 293-297 (2010).
4. Borgenicht, L. & Borgenicht, J. *The Baby Owner's Manual: Operating Instructions, Trouble-Shooting Tips, and Advice on First-Year Maintenance* Quirk Books, Philadelphia, PA (2012).
5. Fomon, S. Infant feeding in the 20th century: Formula and beikost. *The Journal of Nutrition* **131**, 409S-420S (2001).
6. Doucleff, M. Secrets of breast-feeding from global moms in the know. NPR (2017).
7. Scelza, B.A. The grandmaternal niche: Critical caretaking among Martu Aborigines. *American Journal of Human Biology* **21**, 448-454 (2009).
8. Crittenden, A.N. & Marlowe, F.W. Allomaternal care among the Hadza of Tanzania. *Human Nature* **19**, 249-262 (2008).
9. Ivey, P.K. Cooperative reproduction in Ituri forest hunter-gatherers: Who cares for Efe infants? *Current Anthropology* **41**, 856-866 (2000).
10. Petersson, C. Negotiating Reproduction: Family Size and Fertility Regulation among Shuar People of the Ecuadorian Amazon. Doctoral thesis, Goteborgs Universitet (2012).
11. Chapple, A. & Ziebland, S. Viewing the body after bereavement due to a traumatic death: Qualitative study in the UK. *The BMJ* **340**, c 2032 (2010).

HOW TO

TELL

IF

YOU'RE

A

SUPERTASTER

For one thing, you won't like IPAs

by ROB DESALLE

MOST HUMANS CAN BE PLACED into three major categories of tasters—nontasters, tasters, and supertasters, roughly in the ratio of 25 percent: 50 percent: 25 percent. There is also a small percentage (less than 1 percent) of humanity categorized in a super-supertaster category. Supertasters are mostly women, and people of European ancestry are usually not supertasters. So what exactly is a supertaster? You might think that a supertaster would have a lot of fun eating and drinking, but it's more like the opposite. Because supertasters experience tastes more intensely than nontasters and tasters, the effects of different tastes detected by tongues of supertasters are amplified relative to the nontasters and tasters. Super-supertasters have it even worse than supertasters. Taste is a good case of “more is *not* better.”

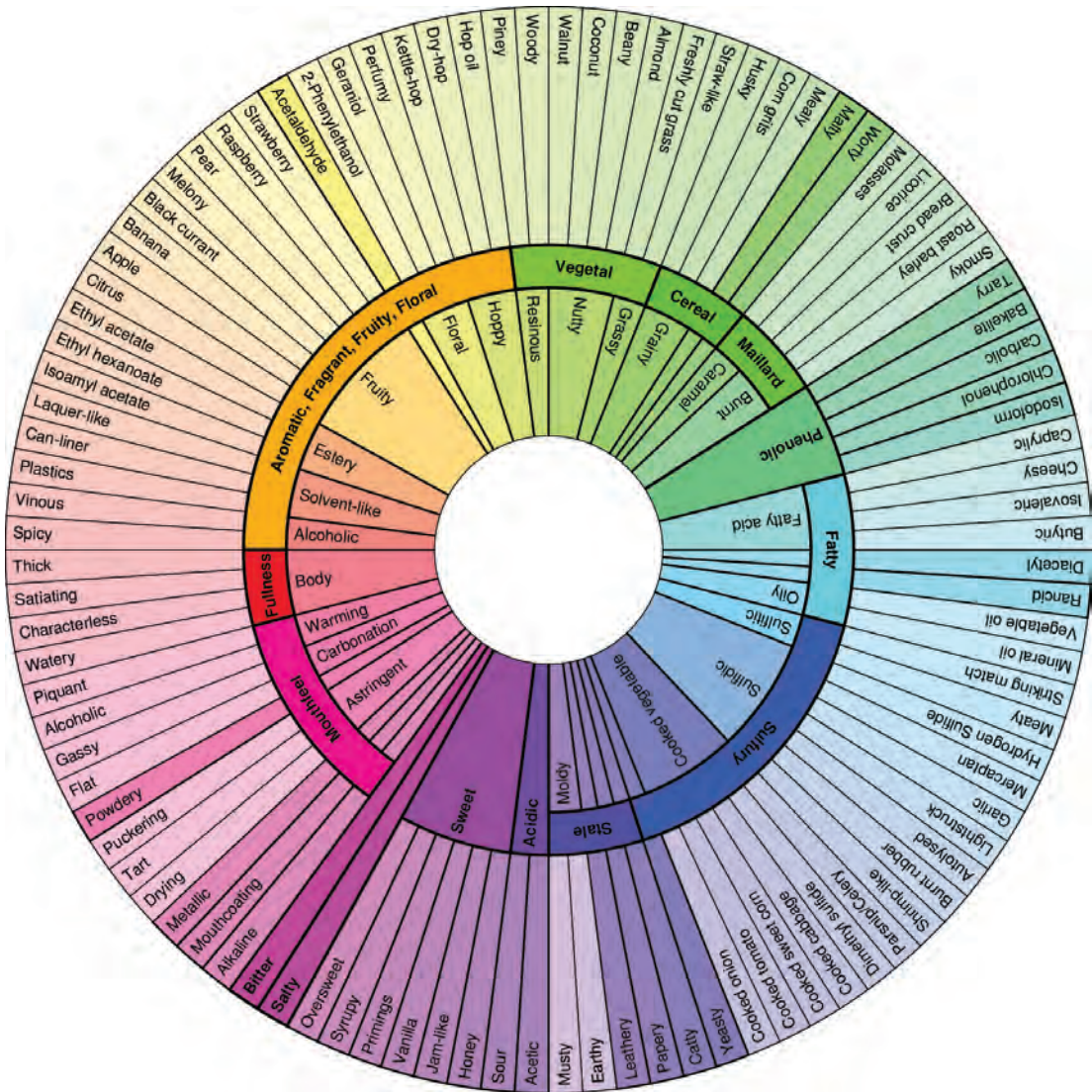
The best way to describe the differences between the categories of tasting is to take one of my favorite beverages to taste—beer—and explain how each of the categories of tasting will respond to this beverage. The Master Brewers Association of the Americas recommend what is called the American Society of Brewing Chemists flavor wheel to help its members assess the taste of their brews. The flavor wheel was created by a co-author of *Sensory Evaluation Techniques*, first published in the 1970s and now in its fifth edition. Morten Meilgaard, a professor of the senses and how to measure them, created the taste wheel to lend a more quantitative aspect to beer tasting.

The taste wheel is quite complex and has gone through many iterations since Meilgaard created it, but it does focus on the complexities of the perception of beer. Examples of the more than 100 possible categories of taste include grapefruit, caramel, farmyard, funky, burnt tire, and baby sick/diapers (which I hope never to taste). It is safe to say that these tastes are the result of many factors, but they all emanate from the very simple contents of beer. In fact, to protect the simple contents of beer, in 1516 Germans created the Bavarian Beer Purity Law, or *Reinheitsgebot*. The purity law forbids any beverage labeled “beer” to be made with anything but hops, water, and barley. Although yeast is needed in brewing, it is a microbe, and was

obviously not recognized as an ingredient 500 years ago. So, the modern concept of taste in most classical beers comes from only four ingredients. The most interesting aspect of the taste of beer, at least to me, comes from the hops and the sugars in the brew, and of course the alcohol that is the product of fermentation implemented by yeast on the sugars from grain.

Although beer is probably several millennia old, hops have been a part of brewing beer for a little more than a millennium. The widespread use of hops began in the last 800 years in Germany and was cemented in brewing technology with the invention of India pale ale (IPA) in the early-to-mid 19th century. With the modern advent of microbreweries and the development of custom-made hoppy beers such as the many IPAs that are on the market, this beverage became one that has a wide range of bitterness. It might be surprising to note that hops were first used as a preservative in beers. The bitter taste from hops is an afterthought. The manipulation of hops today as an integral ingredient in producing craft beers makes for some pretty wildly hoppy beers. (All of which I enjoy immensely, making me more than likely a normal taster.)

Supertasters find beer incredibly bitter, so much so that they will avoid drinking hoppy beers like IPAs and will not be too terribly enamored of even mildly hopped beers, like most lagers. I am also immune to the burn of alcohol in the beer, something that a supertaster will report when his or her lips touch a high-alcohol beer. Suffice it to say, hard liquor is a no-no for supertasters. Nontasters will pretty much drink and eat anything; their tolerance for hoppiness is extreme. But they probably will not be able to tell the difference between a Columbia hopped beer and a Cascade hopped beer. Supertasters should be able to discern quite well between these two hops by taste, but unless they have been conditioned to drink beer, they more than likely will first and foremost consider both as just really bitter. So it is normal tasters who have all the fun with tasting hoppy beer. All of this does not mean that supertasters and nontasters won't enjoy alcoholic beverages. A nontaster will have no trouble gulping down a jalapeño-infused tequila, and a super-taster can be conditioned to drink beer or wine and enjoy those



Taste is a good
case of “more is
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beverages. It has been suggested that upscale chefs are supertasters who have conditioned themselves to overcome the overwhelming effects on their taste buds and to use their supertasting as a tool to create novel dishes. Recently, sour beers or farmhouse ales have become very popular. In this case, brewers of these interesting beers take advantage of the sour taste receptors and combine that with a little hoppiness. Anyone who has tasted a really sour farmhouse ale, though, will recognize that their sour taste receptors are going crazy relative to their bitter receptors.

Tasting beer is really a simple reaction of the small chemicals in the brew with receptor molecules on the tongue. But unlike smell, and although taste is combinatorial, the one thing that dictates whether someone can taste, supertaste, or not taste is ultimately caused by the number of taste cells on the tongue. The taste receptor cells are found in bundles of anywhere from 30 to 100 cells within which the taste receptor proteins reside. The bundles of cells are called taste buds, and most of these reside on physical structures of the tongue called papillae.

There are three forms of papillae on the tongue related to where they reside. The fungiform papillae reside on the anterior region of the tongue, look like little mushrooms budding up from the surface, and can have up to two taste buds per papilla. The circumvallae are located in the posterior region of the tongue, and the foliate papillae are located on the sides of the tongue. Taste papillae are also found on the upper side of the mouth (the palate) and in the throat. Taste cells have also been found in the lungs, but their function in this tissue is unknown.

The density of papillae on the tongue is directly correlated to being a supertaster (more than 30 per 100 mm²), a taster (15 to 30 per 100 mm²), and a nontaster (less than 15 per 100 mm²). In this case, instead of the genes for the taste receptors being the ultimate cause of supertasting, an underlying developmental process is involved. How the tongue develops its papillae has recently been deciphered, and interesting hypotheses about the evolution of the arrangement and number of papillae formed during development are being tested. One immediate result of this work is the discovery of the strange phenomenon that teeth and papillae are patterned with similar genes.

What is an effective technique for examining how many papillae someone has in a given area of the tongue? All of them involve darkening it, and the most enjoyable is to swirl red wine in the mouth and over the tongue. If done correctly, you will be able to see little lumps of tissue on the tongue that are the papillae. Next, take a piece of three-hole notebook paper. The punched holes are about 6 or so millimeters in diameter, and a piece of paper torn off with one of these holes can be placed over the darkened tongue. Now simply count the number of papillae you see in the punched hole. If you have fewer than 4 papillae, you are more than likely a nontaster, whereas from 4 to 8 papillae would suggest that you are a taster. Anything over 8 would indicate that you are a supertaster or a super-supertaster. ☺

ROB DESALLE is curator of entomology in the Sackler Institute for Comparative Genomics at the American Museum of Natural History in New York City. He is author or co-author of dozens of books, several based upon exhibitions at the AMNH, including *The Brain: Big Bangs, Behaviors, and Beliefs* and *A Natural History of Wine*.



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Physics Has Demoted Mass

*Modern physics has taught us
that mass is not an intrinsic property*

BY JIM BAGGOTT

YOU'RE SITTING HERE, reading this article. Maybe it's a hard copy, or an e-book on a tablet computer or e-reader. It doesn't matter. Whatever you're reading it on, we can be reasonably sure it's made of some kind of stuff: paper, card, plastic, perhaps containing tiny metal electronic things on printed circuit boards. Whatever it is, we call it matter or material substance. It has a characteristic property that we call solidity. It has mass.

But what is matter, exactly? Imagine a cube of ice, measuring a little over one inch (or 2.7 centimeters) in length. Imagine holding this cube of ice in the palm of your hand. It is cold, and a little slippery. It weighs hardly anything at all, yet we know it weighs *something*.

Let's make our question a little more focused. What is this cube of ice made of? And, an important secondary question: What is responsible for its mass?

To understand what a cube of ice is made of, we need to draw on the learning acquired by the chemists. Building on a long tradition established by the

alchemists, these scientists distinguished between different chemical elements, such as hydrogen, carbon, and oxygen. Research on the relative weights of these elements and the combining volumes of gases led John Dalton and Joseph-Louis Gay-Lussac to the conclusion that different chemical elements consist of atoms with different weights which combine according to a set of rules involving whole numbers of atoms.

The mystery of the combining volumes of hydrogen and oxygen gas to produce water was resolved when it was realized that hydrogen and oxygen are both diatomic gases, H_2 and O_2 . Water is then a compound consisting of two hydrogen atoms and one oxygen atom, H_2O .

This partly answers our first question. Our cube of ice consists of molecules of H_2O organized in a regular array. We can also make a start on our second question. Avogadro's law states that a mole of chemical substance will contain about 6×10^{23} discrete "particles." Now, we can interpret a mole of substance simply as its

$$\psi = \sqrt{g_{12}} e^{i\theta_{1,2}}$$

$$\psi \delta \mu \delta n \psi - \theta = \theta_0 + \int V(x) dx$$

$$J = J_0 \sin \theta$$

$$g_{12} \frac{\partial \theta}{\partial x} \frac{\partial \theta}{\partial y}$$

$$\sim \frac{m}{f}$$



$$(\vec{p} + e\vec{A} + q\vec{a}) \frac{d}{dt}$$

$$E_1$$

$$e^{-i\epsilon_1 t}$$

molecular weight scaled up to gram quantities. Hydrogen (in the form of H_2) has a relative molecular weight of 2, implying that each hydrogen atom has a relative atomic weight of 1. Oxygen (O_2) has a relative molecular weight of 32, implying that each oxygen atom has a relative atomic weight of 16. Water (H_2O) therefore has a relative molecular weight of $2 \times 1 + 16 = 18$.

It so happens that our cube of ice weighs about 18 grams, which means that it represents a mole of water, more or less. According to Avogadro's law it must therefore contain about 6×10^{23} molecules of H_2O . This would appear to provide a definitive answer to our second question. The mass of the cube of ice derives from the mass of the hydrogen and oxygen atoms present in 6×10^{23} molecules of H_2O .

But, of course, we can go further. We learned from J.J. Thomson, Ernest Rutherford, Niels Bohr, and many other physicists in the early 20th century that all atoms consist of a heavy, central nucleus surrounded by light, orbiting electrons. We subsequently learned that the central nucleus consists of protons and neutrons. The number of protons in the nucleus determines the chemical identity of the element: A hydrogen atom has one proton, an oxygen atom has eight (this is called the atomic number). But the total mass or weight of the nucleus is determined by the total number of protons and neutrons in the nucleus.

Hydrogen still has only one (its nucleus consists of a single proton—no neutrons). The most common isotope of oxygen has—guess what?—16 (eight protons and eight neutrons). It's obviously no coincidence that these proton and neutron counts are the same as the relative atomic weights I quoted above.

If we ignore the light electrons, then we would be tempted to claim that the mass of the cube of ice resides in all the protons and neutrons in the nuclei of its hydrogen and oxygen atoms. Each molecule of H_2O contributes 10 protons and eight neutrons, so if there are 6×10^{23} molecules in the cube and we ignore the small difference in mass between a proton and a neutron, we conclude that the cube contains in total about 18 times this figure, or 108×10^{23} protons and neutrons.

So far, so good. But we're not quite done yet. We now know that protons and neutrons are not elementary particles. They consist of quarks. A proton contains two up quarks and a down quark, a neutron two

About 99 percent of the masses of the proton and neutron seem to be unaccounted for.

down quarks and an up quark. And the color force binding the quarks together inside these larger particles is carried by massless gluons.

Okay, so surely we just keep going. If once again we approximate the masses of the up and down quarks as the same we just multiply by three and turn 108×10^{23} protons and neutrons into 324×10^{23} up and down quarks. We conclude that *this* is where all the mass resides. Yes?

No. This is where our naïve atomic preconceptions unravel. We can look up the masses of the up and down quarks on the Particle Data Group website. The up and down quarks are so light that their masses can't be measured precisely and only ranges are quoted. The following are all reported in units of MeV/c^2 . In these units the mass of the up quark is given as 2.3 with a range from 1.8 to 3.0. The down quark is a little heavier, 4.8, with a range from 4.5 to 5.3. Compare these with the mass of the electron, about 0.51 measured in the same units.

Now comes the shock. In the same units of MeV/c^2 the proton mass is 938.3, the neutron 939.6. The combination of two up quarks and a down quark gives us only 9.4, or just 1 percent of the mass of the proton. The combination of two down quarks and an up quark gives us only 11.9, or just 1.3 percent of the mass of the neutron. About 99 percent of the masses of the proton and neutron seem to be unaccounted for. What's gone wrong?

To answer this question, we need to recognize what we're dealing with. Quarks are not self-contained "particles" of the kind that the Greeks or the mechanical



philosophers might have imagined. They are quantum wave-particles; fundamental vibrations or fluctuations of elementary quantum fields. The up and down quarks are only a few times heavier than the electron, and we've demonstrated the electron's wave-particle nature in countless laboratory experiments. We need to prepare ourselves for some odd, if not downright bizarre behavior.

And let's not forget the massless gluons. Or special relativity, and $E = mc^2$. Or the difference between "bare" and "dressed" mass. And, last but not least, let's not forget the role of the Higgs field in the "origin" of the mass of all elementary particles. To try to understand what's going on inside a proton or neutron we need to reach for quantum chromodynamics, the quantum field theory of the color force between quarks.

Quarks and gluons possess color "charge." Just what is this, exactly? We have no way of really knowing. We do know that color is a property of quarks and gluons and there are three types, which physicists have chosen to call red, green, and blue. But, just as nobody

has ever "seen" an isolated quark or gluon, so more or less by definition nobody has ever seen a naked color charge. In fact, quantum chromodynamics (QCD) suggests that if a color charge could be exposed like this it would have a near-infinite energy. Aristotle's maxim was that "nature abhors a vacuum." Today we might say: "nature abhors a naked color charge."

So, what would happen if we could somehow create an isolated quark with a naked color charge? Its energy would go up through the roof, more than enough to conjure virtual gluons out of "empty" space. Just as the electron moving through its own self-generated electromagnetic field gathers a covering of virtual photons, so the exposed quark gathers a covering of virtual gluons. Unlike photons, the gluons themselves carry color charge and they are able to reduce the energy by, in part, masking the exposed color charge. Think of it this way: The naked quark is acutely embarrassed, and it quickly dresses itself with a covering of gluons.

This isn't enough, however. The energy is high enough to produce not only virtual particles (like a

kind of background noise or hiss), but elementary particles, too. In the scramble to cover the exposed color charge, an anti-quark is produced which pairs with the naked quark to form a meson. A quark is never—but *never*—seen without a chaperone.

But this *still* doesn't do it. To cover the color charge completely we would need to put the anti-quark in precisely the same place at precisely the same time as the quark. Heisenberg's uncertainty principle won't let nature pin down the quark and anti-quark in this way. Remember that a precise position implies an infinite momentum, and a precise rate of change of energy with time implies an infinite energy. Nature has no choice but to settle for a compromise. It can't cover the color charge completely but it can mask it with the anti-quark and the virtual gluons. The energy is at least reduced to a manageable level.

This kind of thing also goes on inside the proton and neutron. Within the confines of their host particles, the three quarks rattle around relatively freely. But, once again, their color charges must be covered, or at least the energy of the exposed charges must be reduced. Each quark produces a blizzard of virtual gluons that pass back and forth between them, together with quark-anti-quark pairs. Physicists sometimes call the three quarks that make up a proton or a neutron "valence" quarks, as there's enough energy inside these particles for a further sea of quark-anti-quark pairs to form. The valence quarks are not the only quarks inside these particles.

What this means is that the mass of the proton and neutron can be traced largely to the *energy* of the gluons and the sea of quark-anti-quark pairs that are conjured from the color field.

How do we know? Well, it must be admitted that it is actually really rather difficult to perform calculations using QCD. The color force is extremely strong, and the corresponding energies of color-force interactions are therefore very high. Remember that the gluons also carry color charge, so everything interacts with everything else. Virtually anything can happen, and keeping track of all the possible virtual and elementary-particle permutations is very demanding.

This means that although the equations of QCD can be written down in a relatively straightforward manner, they cannot be solved analytically, on paper. Also, the

The naked quark is acutely embarrassed, and it quickly dresses itself with a covering of gluons.

mathematical sleight-of-hand used so successfully in QED no longer applies—because the energies of the interactions are so high we can't apply the techniques of renormalization. Physicists have had no choice but to solve the equations on a computer instead.

Considerable progress was made with a version of QCD called "QCD-lite." This version considered only massless gluons and up and down quarks, and further assumed that the quarks themselves are also massless (so, literally, "lite"). Calculations based on these approximations yielded a proton mass that was found to be just 10 percent lighter than the measured value.

Let's stop to think about that for a bit. A simplified version of QCD in which we assume that no particles have mass to start with nevertheless predicts a mass for the proton that is 90 percent right. The conclusion is quite startling. Most of the mass of the proton comes from the *energy* of the interactions of its constituent quarks and gluons.

John Wheeler used the phrase "mass without mass" to describe the effects of superpositions of gravitational waves which could concentrate and localize energy such that a black hole is created. If this were to happen, it would mean that a black hole—the ultimate manifestation of super-high-density matter—had been created not from the matter in a collapsing star but from fluctuations in spacetime. What Wheeler really meant was that this would be a case of creating a black hole (mass) from gravitational energy.

But Wheeler's phrase is more than appropriate here. Frank Wilczek, one of the architects of QCD, used it

in connection with his discussion of the results of the QCD-lite calculations. If much of the mass of a proton and neutron comes from the energy of interactions taking place inside these particles, then this is indeed “mass without mass,” meaning that we get the *behavior* we tend to ascribe to mass without the need for mass as a *property*.

Does this sound familiar? Recall that in Einstein’s seminal addendum to his 1905 paper on special relativity the equation he derived is actually $m = E/c^2$. This is the great insight (*not* $E = mc^2$). And Einstein was surely prescient when he wrote: “the mass of a body is a measure of its energy content.”¹ Indeed, it is. In his book *The Lightness of Being*, Wilczek wrote:

If the body is a human body, whose mass overwhelmingly arises from the protons and neutrons it contains, the answer is now clear and decisive. The inertia of that body, with 95 percent accuracy, *is* its energy content.²

In the fission of a U-235 nucleus, some of the energy of the color fields inside its protons and neutrons is released, with potentially explosive consequences. In the proton–proton chain involving the fusion of four protons, the conversion of two up quarks into two down quarks, forming two neutrons in the process, results in the release of a little excess energy from its color fields. Mass does not convert to energy. Energy is instead passed from one kind of quantum field to another.

Where does this leave us? We’ve certainly come a long way since the ancient Greek atomists speculated about the nature of material substance 2,500 years ago. But for much of this time we’ve held to the conviction that matter is a fundamental part of our physical universe. We’ve been convinced that it is matter that has energy. And, although matter may be reducible to microscopic constituents, for a long time we believed that these would still be recognizable as matter—they would still possess the primary quality of mass.

Modern physics teaches us something rather different, and deeply counter-intuitive. As we worked our way ever inward—matter into atoms, atoms into sub-atomic particles, sub-atomic particles into quantum fields and forces—we lost sight of matter completely. Matter lost its tangibility. It lost its primacy as mass became a secondary quality, the result of interactions between intangible quantum fields. What we recognize

as mass is a behavior of these quantum fields; it is not a property that belongs or is necessarily intrinsic to them.

Despite the fact that our physical world is filled with hard and heavy things, it is instead the *energy* of quantum fields that reigns supreme. Mass becomes simply a physical manifestation of that energy, rather than the other way around.

This is conceptually quite shocking, but at the same time extraordinarily appealing. The great unifying feature of the universe is the energy of quantum fields, not hard, impenetrable atoms. Perhaps this is not quite the dream that philosophers might have held fast to, but a dream nevertheless. ☺

JIM BAGGOTT is a freelance science writer. He was a lecturer in chemistry at the University of Reading but left to work with Shell International Petroleum Company and then as an independent business consultant and trainer. His many books include *Origins: The Scientific Story of Creation*, *Higgs: The Invention and Discovery of the ‘God Particle’*, *A Quantum Story: A History in 40 Moments*, and *A Beginner’s Guide to Reality*.



Adapted from *Mass: The quest to understand matter from Greek atoms to quantum fields* by Jim Baggott. Copyright © 2017 by Jim Baggott and published by Oxford University Press. All rights reserved.

REFERENCES

1. Einstein, A. Does the inertia of a body depend upon its energy-content? *Annalen der Physik* **18** (1905).
2. Wilczek, F. *The Lightness of Being*. Basic Books, New York, NY (2008).

55

WHY SAVE A DROWNING STRANGER? That's the question biologist Rob Trivers asked at the beginning of his classic 1971 paper, "The evolution of reciprocal altruism." The answer, he argued, is that it becomes worth it if you can have the expectation of being saved in the future. The population that selects for altruism and against cheating benefits and outcompetes, and trust gets encoded in its genes.

But trust also appears to be in decline. Trust in government around the world is on the ebb, and is at historic lows in the United States. We're awash in stories of abuse of trust by leaders from all walks of life, especially against women. Younger adults are less trusting than older ones of judges, neighbors, and even in-laws.

It turns out that trust is less of a static currency and more of a battleground. The temptation to cheat is persistent. The rules for calculating the benefits of trusting against its costs are constantly shifting. The costs to the cheater can vary as well—as Trivers put it, "we deceive ourselves the better to deceive others."

Maybe that's why the institution of science has a special role to play in the trust wars, and has maintained the public's trust while other institutions have not. Feynman told us, after all, that "science is a way of not trying to fool yourself."

Welcome to "Trust."

—MS

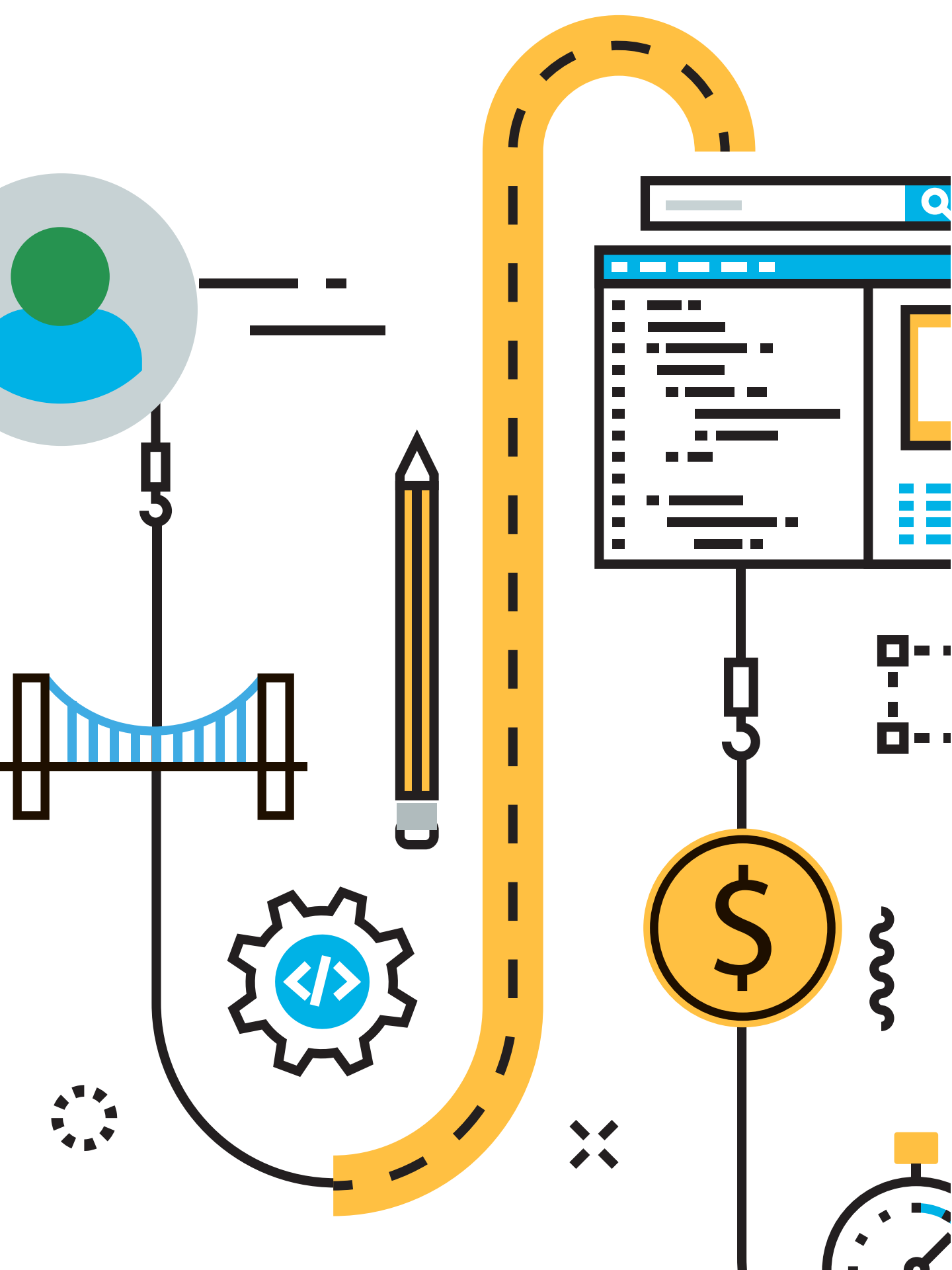
"Finding and fighting bias in data and algorithms also comes with a sliver of opportunity: It can make the outlines of prejudice visible in new ways."

AARON M. BORNSTEIN

"Are Algorithms Building the New Infrastructure of Racism?" p.54

Trust

THE ESSENTIAL INGREDIENT



Are Algorithms Building the New Infrastructure of Racism?

How we use big data can reinforce our worst biases—or help fix them

BY AARON M. BORNSTEIN

WE DON'T KNOW what our customers look like," said Craig Berman, vice president of global communications at Amazon, to *Bloomberg News* in June 2015. Berman was responding to allegations that the company's same-day delivery service discriminated against people of color. In the most literal sense, Berman's defense was truthful: Amazon selects same-day delivery areas on the basis of cost and benefit factors, such as household income and delivery accessibility. But those factors are aggregated by ZIP code, meaning that they carry other influences that have shaped—and continue to shape—our cultural geography. Looking at the same-day service map, the correspondence to skin color is hard to miss.

Such maps call to mind men like Robert Moses, the master planner who, over decades, shaped much of the infrastructure of modern New York City and its surrounding suburbs. Infamously, he didn't want poor people, in particular poor people of color, to use the

new public parks and beaches he was building on Long Island. Though he had worked to pass a law forbidding public buses on highways, Moses knew the law could someday be repealed. So he built something far more lasting: scores of overpasses that were too low to let public buses pass, literally concretizing discrimination. The effect of these and dozens of similar decisions was profound and persistent. Decades later, bus laws have in fact been overturned, but the towns that line the highways remain as segregated as ever. "Legislation can always be changed," Moses said. "It's very hard to tear down a bridge once it's up."

Today, a new set of superhighways, built from data shaped by the old structures, refresh these divisions. While the architects of the new infrastructure may not have the same insidious intent, they can't claim ignorance of their impact, either. Big-data practitioners understand that large, richly detailed datasets of the sort that Amazon and other corporations use to deliver custom-targeted services inevitably contain

fingerprints of protected attributes like skin color, gender, and sexual and political orientation. The decisions that algorithms make on the basis of this data can, invisibly, turn on these attributes, in ways that are as inscrutable as they are unethical.

Kate Crawford investigates algorithmic prejudice at Microsoft Research and co-founded the “AI Now” initiative, a research effort focusing on the dangers posed by artificial intelligence systems as they are being used today. She told me that a fundamental question in algorithmic fairness is the degree to which algorithms can be made to understand the social and historical context of the data they use. “You can tell a human operator to try to take into account the way in which data is itself a representation of human history,” Crawford says. “How do you train a machine to do that?” Machines that can’t understand context in this way will, at best, merely pass on institutionalized discrimination—what’s called “bias in, bias out.”

Incomplete efforts to redress hidden biases can make matters worse. Crawford’s colleague, Solon Barocas of Cornell University, has observed that end users can “uncritically accept the claims of vendors” that algorithms have been cleansed of prejudice. This is particularly true of applications, like the judicial system, where the status quo is rife with prejudice and there is great allure to the promise of more objective machines. Stripping away algorithmic bias can also require privileging one subjective definition of what it means to be fair over another—and what gets chosen is usually whatever is easiest to quantify, rather than the fairest.

For all of its pitfalls, though, finding and fighting bias in data and algorithms also comes with a sliver of opportunity: It can make the outlines of prejudice visible in new ways.

COMPAS IS A PIECE OF SOFTWARE used by courts throughout the United States. The program estimates how likely a defendant is to re-offend based on his or her response to 137 survey questions. This estimate is then used to inform bail decisions.

The COMPAS questionnaire doesn’t ask about skin color, heritage, or even ZIP code. But it does ask questions like whether a defendant lives in a neighborhood with “much crime,” and whether they have had trouble

finding jobs that pay “more than minimum wage.” That these questions are more appropriately posed to a society, rather than an individual, underscores the bias in them: The answers are correlated with protected attributes, including race, which means that algorithms can learn to effectively “see” those attributes in the data. However, Northpointe, the company behind COMPAS, has claimed to have calibrated COMPAS so that the accuracy of its re-arrest predictions is independent of skin color.

In 2016, journalists from ProPublica set out to test this claim using the public records of one COMPAS customer, Broward County in Florida. They found that when COMPAS predicted that a defendant was high-risk, and that defendant was then actually re-arrested, its prediction was indeed colorblind in the most straightforward sense. But when COMPAS’ prediction was inaccurate (either predicting re-arrest when none happened, or not predicting an actual re-arrest) it routinely underestimated the probability of white recidivism and overestimated the probability of black recidivism. In other words, it contained a bias hidden from the perspective of one set of statistics, but plainly visible in another.

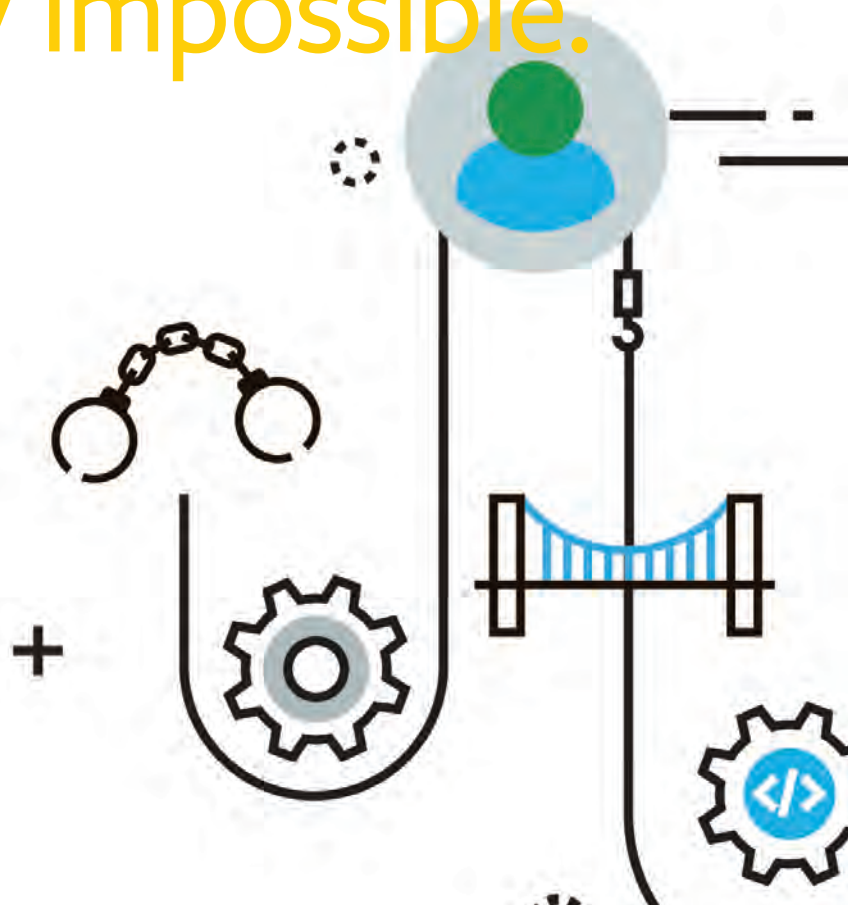
ProPublica reported this finding in an article subtitled “There’s software used across the country to predict future criminals. And it’s biased against blacks.” Northpointe disputed their assessment, and responded with a statistical *re*-analysis of their claims. Northpointe shifted the argument away from the disparity in error rates, instead focusing on the fact that risk scores reflect an actual, underlying prevalence: More African-American defendants do in fact go on to be re-arrested. That means, they argued, that it is not surprising that they have higher risk scores as a population.

At the center of Northpointe’s argument was an essentialist fallacy: Because persons that police classified as African-Americans were re-arrested more often in the training dataset, they claimed, COMPAS is justified in predicting that *other* persons classified as African-Americans by police—even in a different city, state, and time period—are more likely to be re-arrested. The cycling of classification into data then back into classification echoes W.E.B. Dubois’ 1923 definition, “the black man is the man who has to ride Jim Crow in Georgia.”



SOCIAL ENGINEER Robert Moses stands next to a model of the Brooklyn-Battery Bridge in New York City (which was never built).

One of the great benefits of the big data age is that the logic of our decisions can be formally analyzed, and numerically picked apart, in ways that were previously impossible.



While this episode illustrated many of the dangers of algorithmic decisions, it also produced a swell of academic research that came to a surprising conclusion: The very idea of assigning a risk score to a defendant entails a tradeoff between two different and incompatible definitions of the word “fair.” What’s more, this tradeoff is universal. “Any system that carries out this process will have this challenge,” Jon Kleinberg, a professor of computer science at Cornell, tells me, “whether it’s an algorithm or a system of human decision-makers.”

Kleinberg and his colleagues published a study proving that the two definitions of fairness used by Northpointe and ProPublica are mathematically incompatible. In technical terms, what they showed is that predictive parity (whether risk scores have the same overall accuracy for black and white defendants) and error rate balance (whether risk scores get the outcome wrong in the same ways, for different groups) are mutually exclusive. When the base rate of the outcome measure—re-arrest, in the case of COMPAS—is different between any two groups, applying the same standard to both groups will necessarily introduce error rate bias against the group with the higher base rate. “‘Calibration’ is what’s leading to this problem,” Kleinberg said. This is true of any system that uses risk scores—be it machine algorithm or human institution—no matter what factors it uses to generate them.

Remarkably, this incompatibility had never been shown before. Its discovery points to one of the great benefits of the big data age: The logic of our decisions can be formally analyzed, and numerically picked apart, in ways that were previously impossible. As a result, judges now know to consider these kinds of broader imbalances in the decisions they make. “The issues that ProPublica surfaced were really about how we think about prediction, as much as how we think about algorithms,” Kleinberg says.

Academics have also suggested how COMPAS might be fixed. Alexandra Chouldechova, professor of statistics and public policy at Carnegie Mellon University’s Heinz School, has shown that if COMPAS’ designers allow it to be slightly more inaccurate overall for African-American defendants, they can ensure that the algorithm makes mistakes at the same rate for different

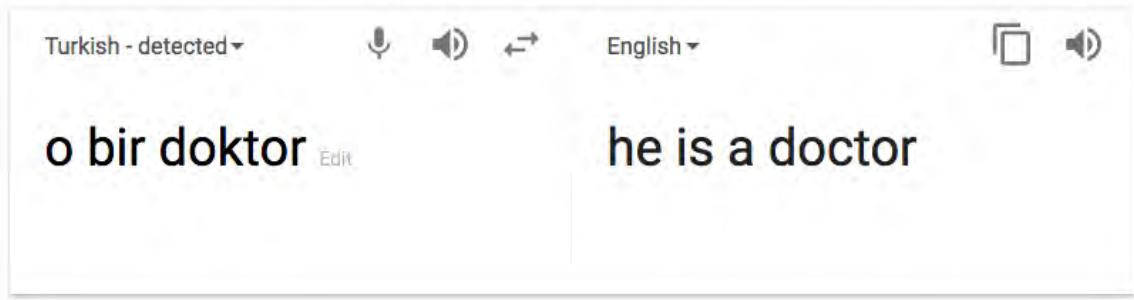
racers. “This,” she observes, “may be a trade-off you want to make.”

GOOGLE TRANSLATE has a hidden sexism. To see it, try translating the phrases “*o bir doktor*” and “*o bir hemşire*” from Turkish to English. Because the Turkish phrases use the gender-neutral pronoun “*o*,” Google Translate is forced to choose a gendered pronoun on its own. The result: It translates the first phrase to “he is a doctor,” and the second to “she is a nurse.”

The translation is described in a 2016 paper by Tolga Bolukbasi and colleagues at Boston University as an example of a type of language model known as word embedding. These models, used to power translation services, search algorithms, and autocomplete features, are trained on collected bodies of natural language (like Google News articles), usually without much intervention from human language experts. Words in the model are mapped as points in a high-dimensional space, so that the distance and direction between a given pair of words indicates how close they are in meaning and what semantic relationship they have.

For example, the distance between “Man” and “Woman” is roughly the same, and in the same direction, as “King” is from “Queen.” Word embedding models can also perpetuate hidden biases, like those in the Google translation. The infrastructure, billions of texts collected in digital corpora over decades, is beginning to inform our daily communication in ways that are hard to understand—and to change. But many of the biases that infrastructure encodes predate their institutionalization in digital form. And, as with COMPAS, studying those biases as they appear in algorithms presents a new opportunity.

Bolukbasi and his colleagues have devised a technique for “de-biasing” language by moving words within the spaces of word embedding models. Imagine placing the words “doctor,” “nurse,” “man,” and “woman” onto the points of a square, with man and woman at the bottom and doctor and nurse at the top. The line connecting doctor and nurse is exactly parallel to that between man and woman. As a result, the system treats their relationship as analogous. Bolukbasi’s debiasing strategy pushes both doctor and nurse to the midpoint of the top edge so that “doctor” and “nurse” are the same distance from “man” and “woman.” The



SEXISM IN TRANSLATION Google translates the gender-neutral Turkish pronoun “o” into “he” when it precedes “is a doctor,” but into “she” when it precedes “is a nurse.” This was first pointed out by computer scientist Aylin Caliskan.

system has, in effect, “forgotten” the analogy; what pronoun the translation might then use is a choice left to the system designers.

The impact of shifting associations between words can be considerable. Arvind Narayanan, a professor of computer science at Princeton University, has developed a tool for measuring prejudice in machine learning models, together with colleagues Aylin Caliskan and Joanna Bryson. The trio began with a much-studied psychological measure called the Implicit Association Test. In a common variant of the test, the greater the speed with which subjects affirm association of positive words with words reflecting social categories, the greater their ease with that association. Across many such pairings, the average difference in response time—usually on the order of milliseconds—is a measure of the degree of implicit bias. Narayanan and colleagues swapped response time for distance between words, creating what they call a word embedding association test. The word embedding association test replicated the same set of stereotypes that Implicit Association Test studies have identified, on the same set of words.

Over two decades, the Implicit Association Test has exposed a wide variety of implicit biases, from gender to nationality to race, across populations and in many different contexts. Because prejudice is so pervasive, some have speculated natural human tendencies—for example to dominance hierarchies, and in-group identification—are responsible for these biases; in this view,

prejudice is an inevitable fact of human nature. The authors of the word embedding association test paper speculate that their work supports another, though not exclusive, possibility: that “mere exposure to language contributes to these implicit biases in our minds.” In other words, if prejudices are reflected, and thus transmitted, in the statistics of language itself, then the way we speak doesn’t just communicate the way we view each other, it constructs it. If de-biasing projects like Bolukbasi’s can work, we can begin to shift our biases at scale and in a way that was previously impossible: with software. If they don’t, we face the danger of reinforcing and perpetuating those biases through a digital infrastructure that may last for generations.

“THE IDEA THAT YOU CAN DO THIS at all is pretty cool,” Narayanan tells me. Still, he wonders how far it can go. He points out that Bolukbasi’s paper assumes that gender is binary, or at least that the connection between gendered words follows a straight line. “I don’t think [we] have any clue of how [debiasing] can work for a concept that is perhaps marginally more complex,” he cautions. He points in particular to racial stereotypes, where the very notion of categories is as problematic as the means used to define them.

When I ask Bolukbasi about this, he responds that the approach can in principle work with any number of categories, though he admits that it does require discrete categories, defined *a priori*. He used crowdworkers recruited from Amazon’s Mechanical Turk (a

service billed as “artificial Artificial Intelligence”) to decide the categories in his gender work. The same workers also evaluated which analogies were biased, and how successful the program was in removing those biases. In other words, the decision about what is biased, and what it means for a bias to be removed, remains deeply tied to the median social consensus, encoding a populist brake on progress.

There are even more daunting concerns. Barocas and Crawford have recently pointed out that most work on fairness in algorithms has focused on what are known as “allocative harms”—the apportioning of resources, such as same-day service, or judgments, such as risk scores. They call for more attention to what critical race scholars like bell hooks’ term “representational harms.” A Google Image search for “CEO,” for instance, produces images that are overwhelmingly of white men. Narayanan says that these problems may be overlooked in discussions of fairness because “they are harder to formulate mathematically—in computer science, if you can’t study something in formal terms, its existence is not as legitimate as something you can turn into an equation or an algorithm.”

In the worst case, these and other limitations on our treatment of bias in data will make the algorithms we are building this generation’s concrete bridges, projecting the status quo forward for years to come. In the best case, data infrastructure will force us to expose and confront our definitions of fairness and decision-making in ways that we might not have done without it.

This tension is difficult to reconcile with our usual notions of technological progress. It’s tempting to presume that technology changes more quickly than society and that software can reinforce social progress by rapidly encoding new norms and insulating them from regressive or malicious actors. A sentencing algorithm can do less harm than a blatantly bigoted judge. But it can also obscure the history and context of bias and hinder, or even preclude, progress. Infrastructure is sticky and the window of opportunity is narrowing: Technology can improve in the future, but we’re making decisions about what trade-offs to make *now*. It’s not clear how often, or even if, we’ll get the opportunity to revisit those trade-offs.

After all, the more pervasive algorithms become, the less likely they are to be replaced. While we might

upgrade our phones every two years, there are strong impediments to renovating core software infrastructure. Consider how much dated technology already permeates our lives—air traffic control systems, for instance, run largely on software built in the 1970s. The recent “WannaCry” worm that crippled hospital systems across the United Kingdom exploited the fact that these systems ran on a decades-old version of Windows, which Microsoft wasn’t even bothering to maintain. A machine understanding of language, embedded in core services, could carry forward present prejudices for years or decades hence. In the words of artist Nicole Aptekar, “infrastructure beats intent.”

The greatest danger of the new digital infrastructure is not that it will decay, or be vulnerable to attack, but that its worst features will persist. It’s very hard to tear down a bridge once it’s up. 🌀

AARON M. BORNSTEIN is a researcher at the Princeton Neuroscience Institute. His research investigates how we use memories to make sense of the present and plan for the future.



The Resulting Fallacy Is Ruining Your Decisions

Are you judging your decisions on their outcomes?

BY STUART FIRESTEIN

INTRODUCTION BY NAUTILUS STAFF

MOST POKER PLAYERS didn't go to graduate school for cognitive linguistics. Then again, most poker players aren't Annie Duke.

After pursuing a psychology Ph.D. on childhood language acquisition, Duke turned her skills to the poker table, where she has taken home over \$4 million in lifetime earnings. For a time she was the leading female money winner in World Series of Poker history, and remains in the top five. She's written two books on poker strategy, and in 2018 will release a book called *Thinking in Bets: Making Smarter Decisions When You Don't Have All the Facts*.

In it, Duke parlays her experience with cards into general lessons about decision making that are relevant for all of us. If a well-reasoned decision leads to a negative outcome, was it the wrong decision? How do we distinguish between luck and skill? And how do we move beyond our cognitive biases?

Stuart Firestein, a professor of neuroscience at Columbia University, sat down with Duke in October to talk to her about life and poker.

How did you get into science?

From when I was very young I set out on an academic path. My parents were both teachers. My dad taught at a small private school in New England. My mother taught at the local public school until she had babies. (It was the '60s, and that was the usual path for women then.) I grew up on the campus of the school and then went to Columbia. I thought I would follow in my father's footsteps and major in English and go on to graduate school. In my family, it was really this idea of, "Where are you going to go to graduate school?" not "if." I ended up double majoring in English and psychology. The whole time I was at Columbia, I worked in Barbara Landau's lab as a research assistant. She was looking at first language acquisition, which was a topic I fell in love with—it's what I ended up studying when I went to graduate school.

What interested you in language acquisition?

You end up studying kind of the whole ecosystem of what learning looks like. What's the brain doing that

it can learn this very, very complex system so quickly? A 1-year-old does very well with new languages, and that's interesting in terms of brain plasticity and learning. Then there's the question of how a baby figures out what goes with what. There are a lot of noises flying around and the child has to figure out what are words and what aren't. Nobody hands the child a map or a key. Then the child has to figure out where the boundaries are. How do you figure out what the end of a word is? How do you figure out what the end of a phrase is? It's really thinking about this very uncertain system. So, I started off very young in my academic career saying, "I'm really interested in these sort of uncertain systems, and how you take feedback in an uncertain system and actually map it properly and try to learn from it."

What was your approach in graduate school?

Landau sent me on my way to Penn to study with Lila and Henry Gleitman, whom she'd studied under. Lila was actually a student of Noam Chomsky, who argues that grammar is built into our brains just like math is. If you have this kind of access to the grammar, it narrows down the uncertainty in the system. I began looking at something called syntactic bootstrapping. The idea was that if the child has access to a built-in grammar, then you can get a long way to actually being able to bootstrap the meaning of words from that. I also looked at the rhythm of mothers' speech to children to show that the rhythm actually mirrors the grammatical structure of the language. That means the child has access to the grammar through the rhythm of maternal speech.

How did you get into poker from academia?

Right at the end of graduate school I got sick. Landed in the hospital for two weeks. Had a very bad stomach problem. Didn't figure out what was wrong with me for a long time. It's something that sort of flares and goes, and flares and goes. But it was right as I was supposed to be going and doing all of my job talks. I called all the places I had job talks at and said, "You know what? I really need to wait a second because I'm sick." So, I delayed everything until the next season. Just rescheduled. So, I went off and had this sort of year off in 1992. I'm like, "Okay. Well, now what am I going to do?" I started playing poker in that year, which sounds kind

of crazy, but it's actually not that accidental because my brother, when he was 18, had moved to New York to study chess. His name is Howard Lederer. And he had moved to New York to study chess with a grandmaster, and actually landed in a poker game along the way. He lost his college fund, which was \$6,300, by the way, but that turned out to pay off really well. By the time he was 21, he was one of the best players in the world. By the time he was 23, he had made the final table of the World Series of Poker. So my brother made the suggestion, "You've got this time off and you need some money. Why don't you try playing poker to make some money while you're waiting to go back?" So, I did, and the wait was 20 years long.

Did you have an instant knack for poker?

I think that I had a big leg up. As part of my training in experimental psych, I had done a lot of statistics and probability work, which is really important to poker. I understood the rigor. And then I had done all this work on uncertainty, and I think that you have to deeply embed yourself in uncertainty in order to become good at poker. And then I also had the advantage of my brother who taught me all those lessons without me needing to lose my college fund like he had. He actually was incredibly helpful and really coached me. I spent a lot of time watching him play.

Do you think you were underestimated as a woman at the poker table, and could you use that to your advantage?

I started playing in Montana, weirdly, because during my time off I got married to a man whose family lived in Montana. So, we went and lived in Montana for a few years and I started playing in these little tiny bars. There was this bar called the Crystal Lounge, and a place across the way called the Monte Carlo. The Crystal Lounge had a poker room in the basement and it was sort of what you'd expect. Ranchers, people who were retired and were on disability, that kind of thing. I can't imagine a lot of them are alive anymore, but if you could find one, I think they would tell you that I was the luckiest person that ever lived. They would not tell you I was any good. That was a big advantage, having them just think I was lucky.



Don't be so hard on yourself when things go badly and don't be so proud of yourself when they go well.

Why is it that luck and skill can be so easily confused?

This is actually a topic that I go into very deeply in my book. I think about it the same way that I was thinking about the way you learn a first language. Now, what does a word apply to? Nobody gives you a map. Nobody tells you, “This was skill,” or, “This was luck.” Say you go through a green light and you get through safely. Was that skill or luck? Well, we know it’s some combination. Trying to figure out what combination is really hard. And that’s a very simple example. You get into these complex situations where the outcome is the result of multiple decisions. Sometimes the decision is incredibly remote from the outcome. I could make a decision about raising my kids or what my disciplinary style is when they’re 5, and not see the results until they’re 18. So, now they’re misbehaving when they’re 18—is it something that I did in the distant past? That gets very complicated. The problem is that you only have the outcome to look at.

How should we deal with the fact that there is so much luck involved in decisions?

Wrap your arms around the uncertainty. Accept it. Know that the way things turn out has a lot of luck involved so don’t be so hard on yourself when things go badly and don’t be so proud of yourself when they go well. Focus on process instead.

Say I have a fair coin. I can tell you exactly what the probability of heads or tails on the next flip is. But I can’t tell you what the next flip will be. That’s what accepting outcomes is like. Accepting that you don’t know if the coin will land heads or tails on the next flip. That means that if you offer me a \$2-to-\$1 gambling proposition on this coin, I should be willing to do that. Even if I lose the next 10 flips, that doesn’t mean that I made a bad decision. And I should strive to be happy that I made a good decision and not focus on the result. It’s a mindset thing.

In life, it’s usually even more complicated because in most real decisions we haven’t examined the coin. We don’t know if it is a fair coin, if it has two sides with a heads and tails on it and is weighted properly. That’s the hidden information problem. We can’t see everything. We haven’t experienced everything. We know the facts that we know, but there may be facts that we don’t know. Then the job of the decider is to reduce



NOT A RESULTER

Annie Duke at the 2007 World Series of Poker.

the uncertainty as much as they possibly can, but to understand that they’re always working within a range and they have limited control over how things turn out on any given try.

What mistakes do we make in evaluating our decisions?

There’s this word that we use in poker: “resulting.” It’s a really important word. You can think about it as creating too tight a relationship between the quality of the outcome and the quality of the decision. You can’t use outcome quality as a perfect signal of decision quality, not with a small sample size anyway. I mean, certainly, if someone has gotten in 15 car accidents in the last year, I can certainly work backward from the outcome quality to their decision quality. But one accident doesn’t tell me much.

In chess, if I lose a game, it's pretty certain that I made a bad decision somewhere and I can go look for it. That's a totally reasonable strategy. But it is a very unreasonable strategy in poker. If I lose a hand, I may have played the hand literally perfectly and still lost because there's this luck element to it. The problem is that we're all resulters at heart. Think about the 2015 Super Bowl. The Seahawks are on the 1-yard line, they're down by four, there's 26 seconds left in the game, Pete Carroll has Russell Wilson throw and it's intercepted. Do you remember what the headlines looked like the next day? "Worst play in Super Bowl history," "What was he thinking?" "Idiot." That kind of thing. But imagine it was caught—what do you think the headlines would have looked like then? The outcome was irrelevant to the decision quality. And just as a teaser, the decision quality was actually pretty brilliant. I won't go into the details of why; you'll have to read my book for that.

Why are we all resulters?

Knowing the outcome infects us. We're rational beings that think things are supposed to make sense. It's very hard for us to wrap our heads around a bad outcome when we didn't do anything wrong. Or that there's a good outcome that's just random. We're really uncomfortable with randomness in that way. It's just the way we're built: to recognize patterns. Which can be bad for decision making in some ways, but is a good thing in others because otherwise we wouldn't be able to recognize our mother's face and then we'd be dead.

How do we stop being resulters?

If we know that outcomes infect us, we want to separate ourselves from outcomes as much as we possibly can when we're thinking about decision quality. And we can really do that. Doesn't matter to me whether you got in an accident or not—I should be able to ask you questions to decide whether your decision quality while you were driving was good, because there's certain things that I do know go into a good decision about driving. You should be sort of trying to think about that for yourself, but also, don't talk about the outcome when you're asking other people about the quality of their decisions. This is something that really great poker players do. If I were to describe a hand to

you that I had a question about, I would give a lot of detail. The kinds of details that I know you need to know. Then I'm going to tell you the decision point. But I may not tell you the decision I made, because that might infect you. And you can go out and do that in your own life. ☺

STUART FIRESTEIN is a professor of neuroscience in the Department of Biological Sciences at Columbia University. He is a fellow of the American Association for the Advancement of Science, a Guggenheim Fellow, and serves as an advisor to the Alfred P. Sloan Foundation.

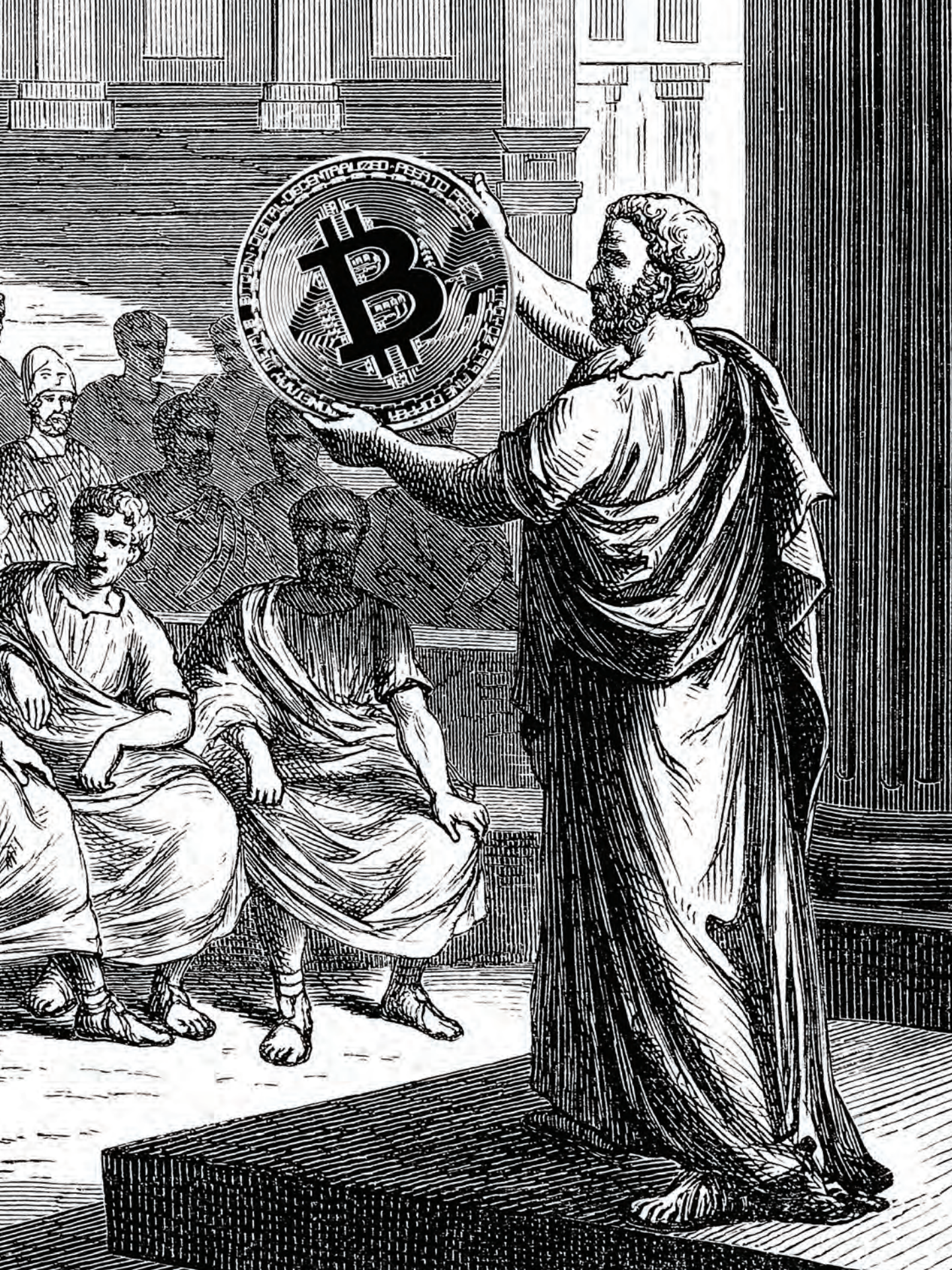
The Bitcoin Paradox

Why cryptocurrency will always be political

by SIMON DEDEO

NASTASIC / GETTY IMAGES; PIXABAY





YOU ARE AN INMATE in a luxury hotel. Locked in your soundproof suite, you hear nothing and see nothing. Liveried butlers bring you meals on silver carts. You have plenty of time to read, think, and listen to music. All the riches of culture can be called down at your whim. But you are trapped, too, and desperate to talk.

One day, you look under your dinner service and discover a note. ARE YOU THERE? You write back, tucking your reply under the plate. YES, WHO ARE YOU, WRITE SOON. In the morning you find replies. It doesn't take long before you realize that notes are being shared, passed, and shuffled, among perhaps dozens of inmates being held in dozens of rooms.

Communication is easy, but it's hard to tell who knows what. Messages pass one another in corridors; conversations fragment. When A replied to B, had she received your message yet, or was she reading C's? Did she ignore what you said because she didn't like it, or because it had yet to be delivered? When D proposes a simultaneous attack on the wardens as they deliver dinner, how many people received it? When A confirms to D that she's in, will D see the message in time? Will D know that B saw it?

Here's one solution, if a strange one. Write a message with a very difficult mathematical problem on it—a problem so hard that it would take a month of concentration to solve. Now wait.

Perhaps nothing happens. But perhaps, just perhaps, you find the answer under breakfast one morning.

THERE'S A ROOM sunk into the ground at the Bandelier National Monument, a few miles from Los Alamos, New Mexico. In plain view for seven centuries, among the ruins left behind by the native peoples who lived there, the circular room, about the size of a high-school classroom, is called a kiva. A bench formed out of straw and mud used to run around the perimeter.

One thing kivas were used for is politics. The circular floorplan made it possible not just for everyone to be heard, but to be seen. When someone spoke in the kiva, he could see his fellows and his fellows could see him. The circle also meant that his fellows could see

each other seeing him; at a glance they could take in not only the speaker, but the faces of their colleagues doing the same.

That matters because politics is not just what you think and believe. If I'm trying to do something that requires your cooperation I need to do more than say I'm willing. I need to know that you know I'm willing.

In cognitive science, we call this common knowledge. To know something is one thing; but to know it with others, know that others know it, and know that they know that you know it, and all the way up the tower—this is another thing altogether. It's what you need for costly cooperation. What teammates on the field and business partners in the boardroom signal when they look each other in the eye is a mental moment at the origin of society.

Common knowledge is power. It is not enough to dislike a government; you need to know that others do, too. When you've built that common knowledge in secret meetings and basement cafes you might go out into the street. In a crowd, common knowledge is obtained without needing to look: The roar of a crowd is a roar an entire crowd can hear.

Totalitarian societies know the power of common knowledge very well. When Gary King's Institute for Quantitative Social Science reverse-engineered the Internet censorship practiced by the Chinese government, they found that the government cared less about insults and criticisms than one might expect. What it censored aggressively were social media posts making plans to meet in person. Online, talk is cheap: but face-to-face people can build common knowledge.

BACK IN YOUR LUXURY HOTEL PRISON, the moment comes: You see an answer to your mathematical problem under your dinner. What does that tell you? At the very least, your message must have reached someone else.

You ponder a bit, and write down a different problem. More than a brainteaser, this one has a funny property: It's impossible to solve except by guess-and-check. And, while it's easy to check whether your guess is correct, it's very hard to find the right guess. If you guessed once a minute it would take you 10 years, say,



BEFORE BLOCKCHAIN The common knowledge enabled by the blockchain used to be created in spaces called kivas; a reconstructed version of one is shown here.

before you got the answer.

A week later, a solution arrives. What does that tell you? For the answer to be struck so quickly, there must have been many people who saw your problem and worked on it. Indeed, somewhere around 500.

Now you're in business. You make a second problem. It has the same properties as the first, plus it incorporates the solution to the first problem. (If you like, imagine that the problem involves a collection of numbers; the new problem takes as one of its numbers the solution of the first.)

You send it back out. You wait. A week later, an answer to the second problem comes back.

What do you know now? Well, as before, you know that a large number of people saw the second problem. And, since the problem included the message from the

first problem, you know that everyone saw that as well, and can reason in a similar fashion. A rough, statistical form of common knowledge has emerged.

As long as you're willing to keep solving problems like this, you can thread together a conversation. If someone wants to reply to you, they can add the solution to your problem to their message. Now you know that the message really is responding to yours, since it couldn't have been written by someone until your message was shared and solved, and when the problem is solved, you know others know it too.

You have started a chain. And every element of that chain, as well as the existence of the chain itself, is common knowledge.

The luxury prison of voices is the Internet. Messages are passed back and forth as Internet packets. Problems

That merger and politics unexpected



of technology produces an paradox



It is not enough to dislike a government; you need to know that others do, too.

are solved by custom-built computing machines. The use of these problems to solve the common knowledge problem is called “Proof of Work.” And the string of messages threaded from one problem to the next is the blockchain.

When common knowledge becomes possible, what will be the first order of business in your communication with your fellow inmates? It will be how to get out, and who will lead the effort. It will be politics.

WHEN I WAS A GRADUATE STUDENT, I was, for a time, in charge of taking lunch orders for a Thursday seminar series (called Thunch, or Thursday Lunch). Students would log onto the central mainframe and use a specially-written command to place an order. Around 11:30 I would print out the order database and ride my bicycle over to the sandwich shop to place it. Accounts were kept in a text file in the mainframe, and once every few weeks I would stroll the halls collecting debts.

For all of the complexity of our financial system, this is basically how money works. People have accounts: a set of numbers, kept in a text file, or a ledger, or a database somewhere at a bank. We agree on rules for how

those numbers change. We serve Thunch.

Bitcoin is a currency that lives on the blockchain. The only messages that can be sent are “transactions,” transfers of a fictitious unit of money, or bitcoins, between accounts. Like any financial system, bitcoin has its own set of rules. No account can go below zero. People who take the time to solve the proof of work puzzle are awarded a unit of currency.*

Currency is just one use of the blockchain. There are lots of others. Ethereum is another blockchain that not only keeps accounts, but also allows users to upload fragments of computer code that govern transfers in increasingly complex ways. Basic government functions, such as the registration and transfer of automobile titles and real estate, the signing of public contracts, and even voting, can be done on blockchain. So can the establishment of new prediction markets that allow participants to bet an internal currency on real-world events.

These are all variations of the conversation at the kiva. Which is to say, they are political. And that merger of technology and politics produces an unexpected paradox.

While blockchains are excellent at forming common

* Proof of work at the scale of bitcoin now is non-trivial and may even be the limiting reagent to the system. The total computer power expended as groups compete to solve the puzzle is equivalent, at time of writing, to the entire nation of Denmark. A single transaction consumes nearly 300 kilowatt-hours—the daily power consumption of 10 residential homes.

knowledge according to a set of rules, those rules are set by hand at the very beginning. Blockchains in place to date do not include a process for amending their constitutions. That means participants are trapped in the logic set by their founders. As systems grow, this constraint leads exactly where you would expect: to disagreement, divergence, and, finally, revolution.

In the world of blockchains, that's called a "fork": When sufficiently many members of the chain want to change the rules, they can go rogue, publicizing a new set of rules and attempting to lure others to divert their computer power to solving proof-of-work problems for their new republic. Forks have happened repeatedly in both bitcoin and Ethereum, usually over technical questions, although Ethereum has also forked over the question of how to respond to looting.

This process is familiar to us from political history. Tribes don't have constitutions, and neither did the monarchies of Europe. Change could be confusing, abrupt, and often violent.

It's easy to become enchanted with the dizzying profits being made with bitcoin, and with the elegance of the mathematics beneath it. But it's dangerous to forget that the point of these systems is to bring the political power of common knowledge into the Internet age, together with all of its potential for disruption and conflict. China's response to the blockchain exemplifies the uncertain landscape. On the one hand, they banned residents from trading on cryptocurrency exchanges—but, on the other, they invest large amounts of money into developing high-speed hardware custom-built to solve proof-of-work puzzles.

The blockchain is no less a social creation than the kiva. We haven't outrun politics yet, and it doesn't look like we will. ☺

SIMON DEDEO is an assistant professor at Carnegie Mellon University, where he runs the Laboratory for Social Minds, and external faculty at the Santa Fe Institute.



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Pictured: João Silveira, DASER alumni, September 2017

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Thursday, March 15, 2018

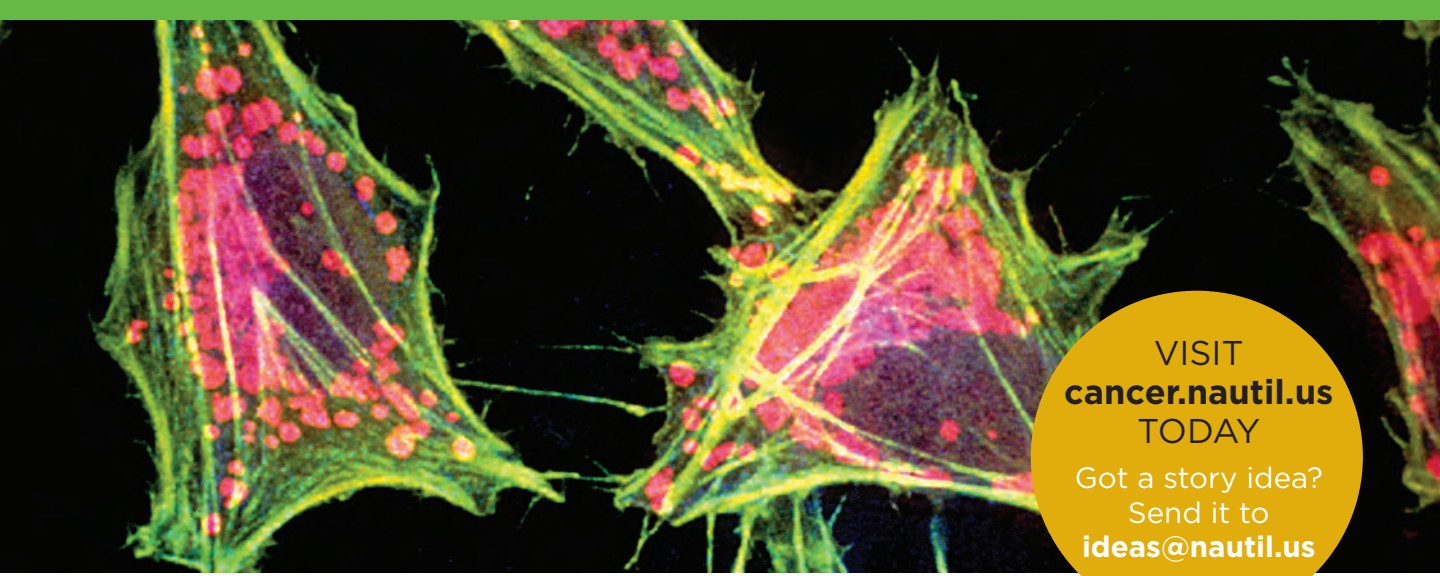
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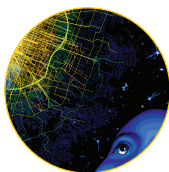
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Susan Pinker

*The developmental psychologist and author of *The Sexual Paradox: Men, Women, and the Real Gender Gap* reflects on the themes in *Nautilus**

INTERVIEW BY BRIAN GALLAGHER

THE UNSPOKEN

In the United States, a woman can't even take off six months with a new baby without losing face, or losing her job. It's not like this everywhere. A senior newspaper editor who interviewed me in the Netherlands when I was on a book tour for *The Sexual Paradox* had a very high-level job, and she worked part-time, which surprised me. I said, "Why do you work part time?" She answered, "Well, Wednesday afternoons is for my aging parents and for my friends. And Friday is for piano. I'm a very serious piano player, and I want to reserve time in my life for something that gives me joy." Protected part-time work might be one of the reasons why Dutch women are happier than American women: They have more career options than we do.

TRUST

There's good research showing that, as a society becomes more egalitarian, the gender differences become much more obvious. One of the studies showing this paradoxical effect is led by David Schmitt, and it shows that gender differences in personality are *way larger* in cultures that offer more egalitarian gender roles and opportunities. This is not what one would predict if men's and women's preferences were exclusively constrained by cultural forces. Assuming that women are simply a tamped down, smothered version of men—and would always choose what men choose if they only had the chance—is neither respectful of women's autonomy nor supported by the data. ☺



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