BRAIN DEVELOPMENT
How Babies Rapidly Learn Language

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Nanotech That Diagnoses Disease

AGRICULTURE
Threat to Olives from Bacteria?

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Art and Archeology in the Ancient World

Speaker: Diana McDonald, Ph.D.

Olympia: Games for the Gods

Olympia is famous today as the origin point of the Olympic Games in 776 B.C. Learn about the art that this Greek "culture of competition" inspired, the way artists glorified athletes and fighters, and the link between warfare, sports, and religion. Finally, investigate how Olympic art may have influenced modern attitudes toward sports and athletes.

Athens: The Acropolis and the Parthenon

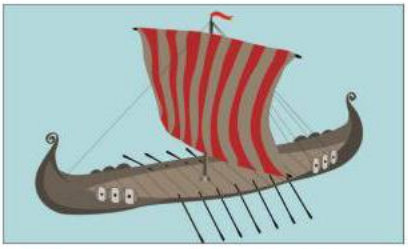
Many consider the Parthenon the most perfect building ever created. How did it reach those heights? We'll see how the crowning glory and symbol of Classical Age Greece was the result of a long development in architecture and a refinement of the principles that underlay Greek culture and ideology.

Ephesus: The Temple of Artemis and the Goddess Cults

The Temple of Artemis of Ephesus is said to have been founded by Amazons, and was a center for goddess cults and an emblem of women's importance in the ancient world. We'll look at the famous many-breasted sculptures of Artemis, and link her to her forebears from the Neolithic and Bronze Age worlds.

Santorini: The Early Cultures of Greece

The eruption of Thera (circa 1500 BCE) was one of the largest catastrophic volcanic events on Earth. Did this eruption incite the subsequent collapse of the Bronze Age Minoan civilization? Learn about this enigmatic early island culture, including its elegant art and still undeciphered script, and what we know of its downfall.



A Review of the Ancient Mediterranean Civilizations

Speaker: Kenneth W. Harl, Ph.D.

Sea Power in the Ancient Mediterranean

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Struggle for the Mastery of Greece, 480–338 B.C.

Learn why the Athenian city-state gave way to a united Greece. We'll tackle compelling questions such as, was civil war inevitable? Did an oligarchy like Sparta have advantages over a democracy like Athens? And why, in spite of bringing peace and unity, were the Macedonian Philip II and Alexander the Great hated as oppressors?

Constantinople to Kostantiniyye

Survey the evolution of Constantinople from Byzantium, a part of "old Rome," into "New Rome," through the glorious flowering of the Byzantine Empire, the destruction by the Crusaders, and the city's rebuilding by the Ottoman Turks. We'll look at the people and the societal factors behind this turbulent progression.

Markets, Trade, and Money in the Mediterranean World

As we travel the Aegean, learn where the money that created its architectural and culcultural artifacts came from and where it went. We'll investigate the invention and use of coins, the use of credit and banking, and the role of cities in economies to understand the economic systems of the Mediterranean world.

Religious and Cultural Change in Anatolia

Turkey's landmarks tell a story about how Anatolia's religious landscape has been successively rewritten. Experience the sweep of Anatolian history, from the first known Neolithic village where the roots of future gods Zeus and Cybele lie, to the creation of secular Turkey, and gain a context for Asia Minor's cultural highlights.

Theoretical Physics

Speaker: Tara C. Shears, Ph.D.

The Power of Symmetry

In ancient Greece Plato thought that symmetry was related to harmony and beauty, and we have associated symmetry with the universe's nature ever since. Learn how modern scientists have found that symmetries are intimately linked to invariances, conserved quantities and the physical laws of nature.

The Particle Physics World

The modern theory of particle physics, the Standard Model, is so good that we haven't yet made a measurement that disagrees with it. It is our most successful fundamental theory ever—but we think it isn't correct. We'll explore what we understand about the subatomic world and what makes physicists think we're missing something.

Antimatter

Antimatter sounds like science fiction but it's actually science fact. According to our theories, matter and antimatter should be symmetric and behave identically, but experimentally we find this symmetry doesn't quite hold. Learn why antimatter is one of the greatest mysteries in physics and what we're doing to try to solve it.

Toward an Ultimate Theory of the Universe

Physicists' preference for a simple, symmetric universe has got us this far and left us with a list of outstanding mysteries: antimatter, dark matter, even gravity. Can symmetry help us out again? We'll survey the theories invoking new symmetries in nature that might explain more, and discuss experimental ways to test them.

Architecture in the Ancient World

Speaker: Stephen Ressler, Ph.D.

Building in Stone: From Quarry to Temple

How were the stones for buildings like the Parthenon extracted with only iron-tipped picks? How were they shaped with only hand tools, and then positioned with such precision? We'll answer these questions by following a block of stone from its point of origin to its final resting place in the wall of a Greek temple.

Stone Masonry Perfected: The Greek Temple

The colonnaded temple was one of the crowning achievements of Classical Greek civilization. But where did this iconic structure originate? Learn how the familiar architectural form was strongly influenced by the structural limitations of its post-and-lintel structural system, and how later Roman engineers overcame these limitations to open new realms of architectural possibility.

Roman Engineering at Ephesus

The Romans were the most accomplished engineers of the ancient world and the city of Ephesus offers ample evidence of their engineering prowess. We'll examine Roman arches, vaults, water systems and bath complexes as engineered systems and explore some of the many examples of these technologies that have survived in Ephesus today.

The Church of Hagia Sophia

Hagia Sophia, the Church of Holy Wisdom, is the world's most majestic example of Byzantine architecture. Learn about the mechanics of its great central dome and how its integrated system of columns, arches, vaults, semi-domes and buttresses supports the dome while simultaneously creating an interior space of incomparable grandeur.

Reconstructing the Trireme

The trireme was a 125-foot-long wooden warship, rowed by 170 men arrayed on three levels, used in battle as a human-powered torpedo. We'll examine this extraordinary technological system, and how, by the fifth century B.C., it had become the principal means of asserting political power in the eastern Mediterranean.

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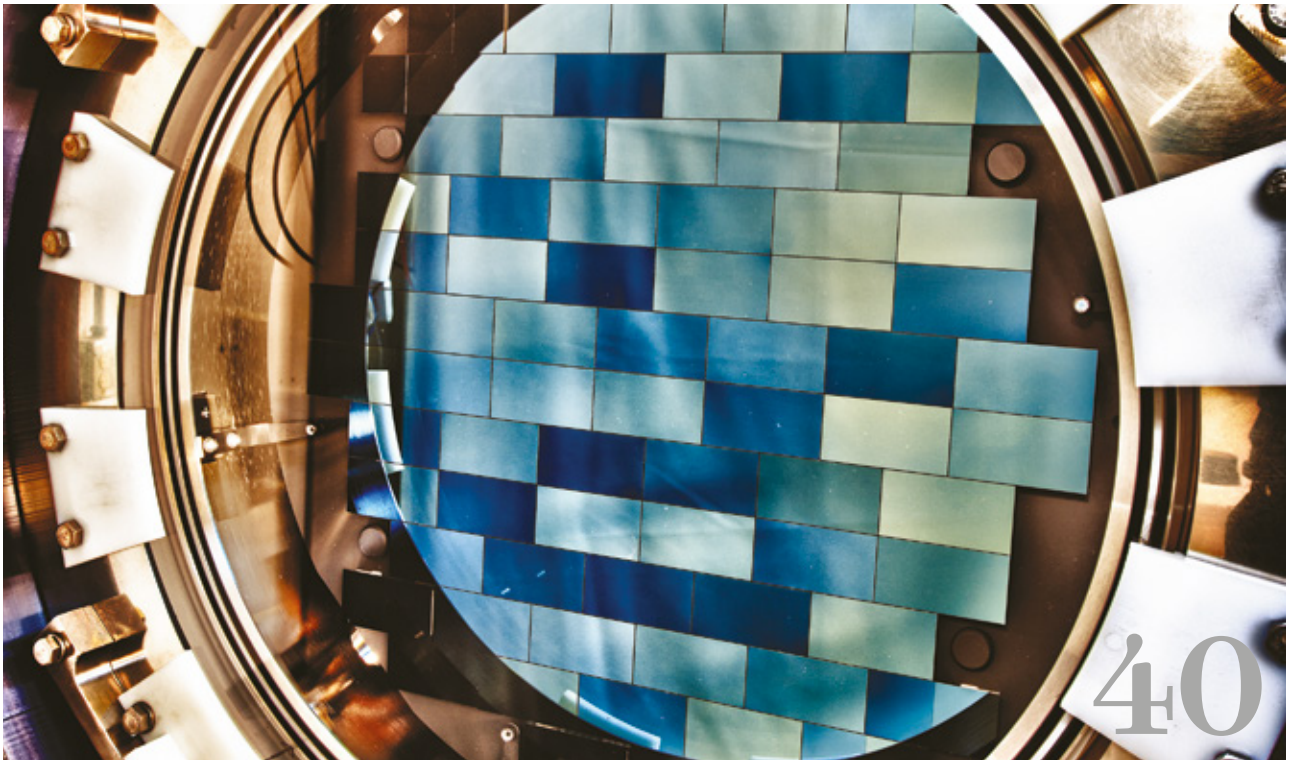

ON THE COVER

Recent archaeological discoveries are providing insights into the people who erected Egypt's Great Pyramid. The trade and labor infrastructures developed to build the monument, which would serve as Pharaoh Khufu's tomb, ushered in a centuries-long period of prosperity for Egypt that also benefited its trading partners abroad. **Photograph by Shanna Baker, Getty Images.**

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ON THE WEB

Sustainable Development
Scientific American provides perspective, context and criticism of the United Nations's recently adopted Sustainable Development Goals.
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Know Your Net Worth
How Do You Stack Up?

Why Knowing Your Net Worth Is Essential

If you are close to retirement or already retired, knowing how much you are worth is essential. It will help you realistically determine the kind of retirement you can actually afford as well as help you select the best financial strategies to grow, protect and distribute your wealth.

How Do You Stack Up?

You'll find out where you rank in terms of total net worth and liquid net worth compared to others. Plus, if you have liquid net worth of over $500,000, you'll learn of some investment options that are now open for you as well as which ones are probably not right for someone of your financial standing and achievement.

Learn the Real and Hidden Retirement Investment Risks That Most People Ignore...Until It Is Too Late

In *Your Net Worth* we also share what we consider to be the five biggest wealth killers. You'll learn what they are and how to avoid them and their consequences. Surprisingly, some of these threats to your wealth are exactly what some financial "experts" recommend! Finding this out could save you thousands of dollars and prevent you from making some financial decisions that could threaten your retirement lifestyle.

Don't Run Out of Money in Retirement

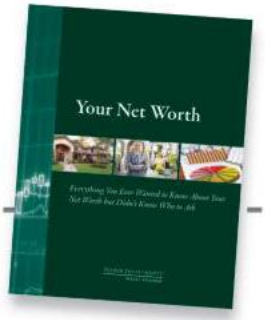
With people living longer, with health care and long-term care costs continuing to rise and with general inflation eating away at your wealth in a slow but insidious way, now is the time to learn what steps you should and shouldn't take. It pays to understand the dangers as well as the options.

About Fisher Investments and Ken Fisher

Fisher Investments is a money management firm serving successful individuals as well as large institutional investors.

With over $65 billion* in assets under management and a track record of over 35 years in bull and bear markets, Fisher Investments uses its proprietary research to manage money for investors.

Ken Fisher, Founder, CEO and Co-Chief Investment Officer, has been *Forbes*' "Portfolio Strategy" columnist for over 30 years and is the author of more than 10 financial books, including 4 *New York Times* bestsellers.



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Mariette DiChristina is editor in chief of *Scientific American*. Follow her on Twitter @mdichristina

Pyramids, Olives and Young Minds

Perhaps it's natural, given the scale of these massive Egyptian icons of stone, that archaeologists have long focused on the construction methods and engineering used to create the Giza pyramids. Now we are at last learning that behind the heavenward movement of the looming tombs, there is an equally remarkable rise: that of an intricate and far-flung social network.

New discoveries are revealing the real secrets of success for the pharaohs: government, labor and trade infrastructures that not only got the pyramids built but also set the stage for centuries of Egyptian prosperity and shaped the growth of civilization. The trade networks drew wealth to Egypt and powered the economies of its trading partners abroad. Turn to page 32 for our cover story, "The Pyramid Effect," by Zach Zorich.

Modern trade—in olives and their precious oil—is thought to be under threat from a bacterial scourge, *Xylella*, being ferried by insects across groves in southern Italy. Whereas some have called for the seeming reliability of mass cuttings as a solution to prevent further spread, scientists remain uncertain about exactly how—or even whether—the bacterium is actually at fault for damaging the trees of Puglia. "Hard data are scarce," writes Barbie Latza Nadeau in "The Battle of Olives," starting on page 52, "so the scientists and local authorities tend to stay silent, which many growers interpret as a cover-up for ulterior motives."

As scientists, farmers and officials struggle to bridge a gap in perception and shared understanding about a shared problem in the absence of sufficient data, I reflect on the paradox presented by "Baby Talk," by Patricia K. Kuhl, beginning on page 64: that kind of communication is child's play ... for youngsters. We are born with a fleeting ability to understand and master any of the world's 7,000 languages. Infants of just a few months of age can pick up the unique acoustic properties of languages from around the globe and speak in full sentences just a couple of years later. After the age of seven, fluency in a second language becomes more elusive. As always, I find myself marveling at the power of children to give us adults a lesson; see the accompanying box for more on that. SA

Google Science Fair Winners

Now in its fifth year, the Google Science Fair draws entries by students ages 13 to 18 from around the globe. *Scientific American*'s $25,000 Innovator Award, for projects in biology, chemistry, physics or the behavioral sciences, went to Krtin Nithiyanandam. We also recognized Lalita Prasida Sripada Srisai with a $10,000 Community Impact Award. Both honors come with a year of mentoring and access to our 170 years of digital archives for the winners' schools (ScientificAmerican.com/education). —*M.D.*

Illustration by Nick Higgins

Nobel laureates in their own words

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DARK MATTER

"Mystery of the Hidden Cosmos," by Bogdan A. Dobrescu and Don Lincoln, discusses the possible forms of dark matter.

Could a potential explanation of dark matter not involve new particles? Could, say, gravity decrease with distance slightly less than described in Newton's laws, noticeable only on a scale of light-years? And have scientists tried to quantify this possibility in a way that could explain galaxies' rotational speed without dark matter?

MARTIN LICKA
Cornellà del Terri, Spain

The universe is believed to have additional mass, which the article assumes exists in the form of unknown particles. Maybe the search shouldn't be limited to our own universe. We might be merely constrained to a subuniverse of *X, Y, Z* and *T,* whereas nearby similar subuniverses exist along a fifth axis of *W.* A weak,balanced gravitational coupling between the subuniverses could create an increase in the apparent mass of our own structures, undetectable at small scales but significant at very large ones.

DAVID L. KRIMM
Lexington, Ky.

THE AUTHORS REPLY: Regarding Licka's question: The possibility of modifications to the equations relating force and inertia (called MOND, for modified Newtonian dynamics) can explain the rotation curves of galaxies and some other discrepancies but not all of them. New MOND theories still require some residual dark matter to explain observations, so the dark matter hypothesis accurately describes the data with fewer assumptions. Per Occam's razor, the simpler theory is likelier correct.

Both of us once wondered if the scenario Krimm suggests might be true, but it is not if the additional dimension is large. If there exist parallel, overlapping and mostly noninteracting universes, then each one consists of four infinite spatial dimensions. We have measured the dimensional behavior of gravity and have seen that it expands to fill our three spatial dimensions. To look like dark matter, gravity would have to expand into all four dimensions, which would mean that the gravitational force between two objects would decrease as the third power of separation.

"Police who are driven to kill unarmed citizens through fear should find other employment."

HARRY J. FOXWELL *FAIRFAX, VA.*

POLICE WHO KILL

In "Outrageous" [Skeptic], Michael Shermer credits the brain's rage circuitry to explain "why cops kill." But there's a more direct explanation: police can employ lethal force and are trained to use it by default to protect themselves rather than making the safety of the citizenry their highest priority. A partial solution is to equip and train police primarily with nonlethal weapons and require a prime directive that citizens' lives are to be preserved even at the risk of their own safety. Police who are driven to kill unarmed citizens through fear should find other employment.

HARRY J. FOXWELL
Fairfax, Va.

I am worried about Shermer's skepticism if it's his understanding that these killings of black men by police are a "rash" of incidents or that prejudice "to whatever extent ... still percolates in the minds of a few cops in a handful of pockets."

What has always been the harshest, most feared reality for some can now be witnessed by all of us on television. Video cameras are the only new actors in these scenes—which happen all the time nationwide and, if no civilians are around, are still almost always covered up.

LYNN WITHERINGTON
Berkeley, Calif.

SHERMER REPLIES: There is no national database on how many people are killed by police each year, and reports by the nation's 18,000 individual police departments are voluntary. With a reporting rate of less than 3 percent, estimates are considered unreliable by scholars who study violence. Thus, using reliable data to assess whether police violence is increasing is not currently possible.

A study by the Washington Post *recorded 694 people killed by police by mid-September this year, compared with a crude estimate (possibly an underestimate) of about 400 a year during the past decade. Blacks make up 13.2 percent of the population but 26 percent of this cohort. Updated data, including many more details, can be seen at http://wapo.st/1LFzepU.*

It is possible that there is an upward trend line that confirms our intuitions, but an unfortunate by-product of the moral panic in response to the media coverage of the topic is that the police have been hampered from doing their job, and in many cities we have seen an uptick in homicide rates after a 23-year decline. In any case, we need more and better data. In the meantime, police training in how to defuse potentially violent situations and the use of body cameras are a good start.

UNDER PRESSURE

In reporting on exploration below the West Antarctic Ice Sheet in "Life at Hell's Gate," Douglas Fox refers to "extreme pressure" exerted on the water by the mass of the ice above the grounding zone. But does not hydrostatics dictate that the pressure of the water in this zone depends only on its depth? The ice above the water should have no influence on the pressure.

JOHN JAMESON
El Cerrito, Calif.

FOX REPLIES: The patch of Antarctic coastal seafloor that was explored in January sits about 700 meters below sea level (much of the continent's hidden rock-and-sediment surface sits far below sea level, in part because of the weight of the ice pressing on the earth's crust). Based on that depth alone, the pressure would be about 70 atmospheres.

Depth below sea level does indeed provide a good shortcut for estimating subglacial pressure in coastal areas of Antarctica, where the ice is floating. Further inland, however, where the ice is thick enough that it rests directly on the continent rather than floating, the best way to estimate pressure under the ice is to begin with the thickness of the ice itself, corrected for its lower density relative to water.

PEROVSKITES FOR SOLAR

"Outshining Silicon," by Varun Sivaram, Samuel D. Stranks and Henry J. Snaith, discusses how perovskite could replace crystalline silicon in the manufacture of solar cells. Was it deliberate that the article avoided explaining what perovskite is?

DONALD E. SANDS
Lexington, Ky.

SIVARAM REPLIES: Photovoltaic researchers use "perovskite" for compounds that share the crystal structure of a calcium titanate ($CaTiO_3$) mineral that was discovered in Russia in the 19th century.

The solar perovskites we discuss are organic-inorganic hybrid compounds that crystallize from organic halide and metal halide salts to form crystals in an ABX_3 structure—A is the organic cation (positively charged ion), B is the metal cation and X is the halide anion (negatively charged ion). Adjusting the chemical composition of the perovskite layer enables researchers to tune the electronic, optical and physical properties of the solar cell.

ERRATUM

"Blitzkrieg Basics," by Tim Palucka [Advances], wrongly states that Germany engaged in a blitzkrieg of Stalingrad in 1941. It should have referred to Germany's invasion of the Soviet Union as whole, which began in 1941. The Battle of Stalingrad began in 1942.

LETTERS TO THE EDITOR

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A Risky Arms Race in Space

Superpowers are flexing military muscles in orbit, but the U.S. can lead the world away from a planetary disaster

By the Editors

On January 11, 2007, with no warning, China's military fired a ballistic missile at one of the country's weather satellites and blew it to bits. China's first test of an antisatellite weapon made a mess: tens of thousands of metal shards now litter low-Earth orbit, where the International Space Station, other crewed missions and about half of all operational satellites fly.

Other superpowers have been exploring space-based weaponry. In October 2014 the U.S. Air Force's X-37B Orbital Test Vehicle–3 returned from a mission where some analysts believe it was testing technologies for hypersonic missiles—weapons capable of hitting any target on Earth within an hour—and, possibly, techniques for repairing or disabling satellites. Russia has tested three satellites in recent years that may be able to intercept other orbiting spacecraft to eavesdrop on or physically sabotage them.

This militarization of space is a dangerous course. A small skirmish above our planet could knock out global communications, and the orbiting hazards could lock off access to space for generations. Worse, attacks on satellites could quickly escalate into war on the ground. World powers need to act now to declare space a demilitarized zone.

In 2008 China and Russia made a motion in that direction by proposing a United Nations treaty that would ban weapons in space. But the draft contains no verification process and makes no mention of the kind of Earth-based satellite-killing technology China has been testing. It has been a nonstarter in the U.S. not only because of its loopholes but also because Congress is deeply hostile to any treaty that places limits on the American military. U.S. opposition, joined by that of other balking countries, dooms any U.N. treaty, which would require unanimous approval from all members of the conference in which it is introduced.

This year a more feasible alternative proposed by the European Union was discussed at a disarmament conference. The nonbinding International Code of Conduct for Outer Space Activities calls on countries to maintain the area around our planet as a peaceful global commons, and it sets out practical guidelines for avoiding collisions in space and for minimizing and removing debris. Michael Krepon, co-founder of the Stimson Center, a global peace and security think tank, explains that the code of conduct is modeled on cold war measures such as the Incidents at Sea Agreement between the U.S. and the Soviet Union, which in 1972 established rules for military forces operating in close proximity. Another U.S.–Soviet Union pact, signed in 1989, set expectations for troops using laser range finders, as well as radio channels that could jam other frequencies, actions that could easily be interpreted as hostile. These were not binding treaties, but the U.S. and the Soviet Union adhered to them, and they helped to prevent disaster. This time, however, Russia, China and several other nations have said they will not abide by the E.U.'s proposed space code because they were left out of the drafting process, and they object to some of the code's provisions.

The E.U. should adopt the International Code of Conduct for Outer Space Activities anyway, and the U.S. should join them at the launch. The history of cold war agreements suggests other nations—perhaps eventually even China and Russia—will follow out of self-interest. Nobody wants its satellites destroyed, and in the absence of a treaty, shared standards of nonaggression are just about the only way to achieve that goal. Even the greatest superpower's satellites are easy targets for a motivated attacker, so the best defense is for everyone to agree not to shoot.

Given the alternatives—placing all chips on the vanishingly small possibility of a binding U.N. treaty or doing nothing and hoping for the best—an international code of conduct looks like the best strategy. The Obama administration, Europe and their allies should lead by example and start operating by these standards as soon as possible. International norms have prevented catastrophe before, and they can do it again. SA

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Illustration by Michael Manomivibul

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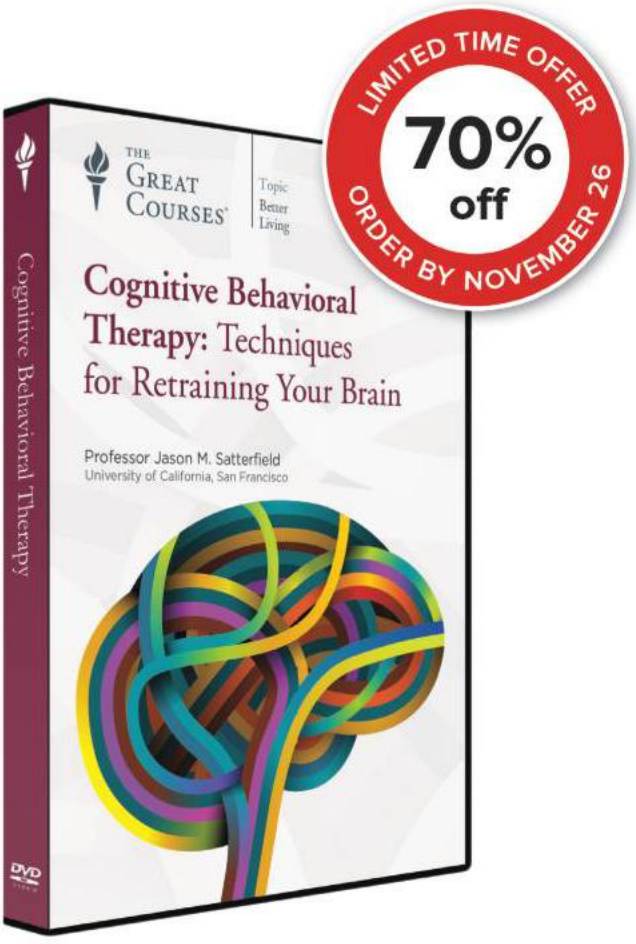

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Racial Bias in Medicine

To tackle it, doctors need to think hard about what it means to be "objective"

By Rachel Pearson

Medicine has a race problem. Doctors consistently provide worse care to people of color, particularly African-Americans and Latinos. In studies that control for socioeconomic status and access to care, researchers have found racial disparities in the quality of care across a wide range of diseases: asthma, heart attack, diabetes and prenatal care, to name a few. Two studies performed in emergency rooms showed that doctors were far more likely to fail to order pain medication for black and Hispanic patients who came in with bone fractures. Doctors are less likely to diagnose black patients with depression yet more likely to diagnose psychotic disorders such as schizophrenia. Hispanic HIV patients are twice as likely to die as white HIV patients, and black HIV patients are less likely to get antibiotics to prevent pneumonia. There is, however, one procedure that doctors are more likely to perform on black patients: amputation.

As a medical humanities M.D./Ph.D. student, I set out to understand how my profession, which prides itself on objectivity, could be influenced by something so subjective and harmful as racial bias. I found part of the answer in the kind of objectivity that doctors value. As trainees, we aspire to be like scientists, who see the self as a potential source of error and therefore try to suppress it. But medicine is not a science—it is a moral practice that uses science. When problematic parts of ourselves, such as racial bias, intrude, we find it hard to recognize the problem.

In studying memoirs of medical students and residents, I found that many trainees feel an acute anxiety about the self. When we react emotionally to intense situations, we worry that we are not being good doctors. When we do not react—when we coolly watch a patient die or approach a critically ill child with clinical detachment—we worry that we are becoming monsters. We are unsure of the role emotions should play in clinical care. Interestingly, one specific emotion—discomfort—is thought to underlie disparities in care. Feeling uncomfortable, we rush out of encounters with patients of other races.

I was surprised to find that white trainees rarely mentioned race in their memoirs, even though we are disproportionately likely to care for patients of color in the free clinics and public hospitals where we learn. In medical school, we come to see race as a biological fact: something that predisposes certain patients to certain diseases. Medical students and residents of color perceive race differently—as a social experience. Former U.S. surgeon general Joycelyn Elders recounts being barred from the cafeteria when she was in medical school, and internist Rameck Hunt relates being unjustly arrested when he was a first-year med student. Navajo surgeon Lori Arviso Alvord writes about how touching a dead body in an anatomy lab course violates a Navajo taboo. Students of color also report feeling profoundly supported by their communities, and many are inspired by their own experiences of prejudice to provide excellent care to patients of color.

If white medical trainees avoid talking about race except as a biological fact, how can we explore racial bias? We might begin by revising our model of objectivity. Doctors are always themselves—emotional, particular and sometimes biased—in the hospital. We should accept this fact and learn to work with it. We should train ourselves, for example, to notice our own discomfort and respond by slowing down instead of rushing out of patient encounters. (Some medical schools are now training students to do just that.)

Other commonsense measures to tackle bias in care include aggressively recruiting and retaining medical students who reflect the diversity of the nation, explicitly training physicians to recognize unconscious bias and fairly promoting physicians of color within academic medicine. Ultimately, however, I hope that revising our understanding of objectivity in medicine can do more than just address bias. Medicine could be—it should be—a tool for ensuring that all people's lives are cherished. If we doctors begin to earn our authority as science-using moral leaders, then both medicine and society have much to gain. SA

Rachel Pearson is an M.D./Ph.D. candidate who will graduate in 2016 from the Institute for the Medical Humanities at the University of Texas Medical Branch at Galveston. For five years she volunteered at and directed one of the largest student-run free clinics in the country. Her book *No Apparent Distress* is forthcoming from W. W. Norton.

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Illustration by Edel Rodriguez

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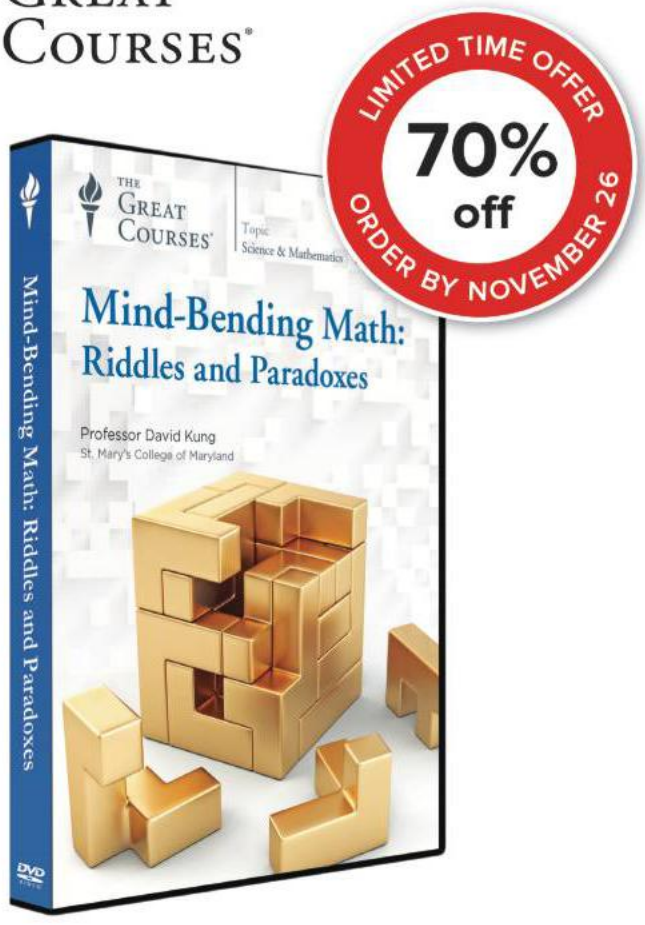

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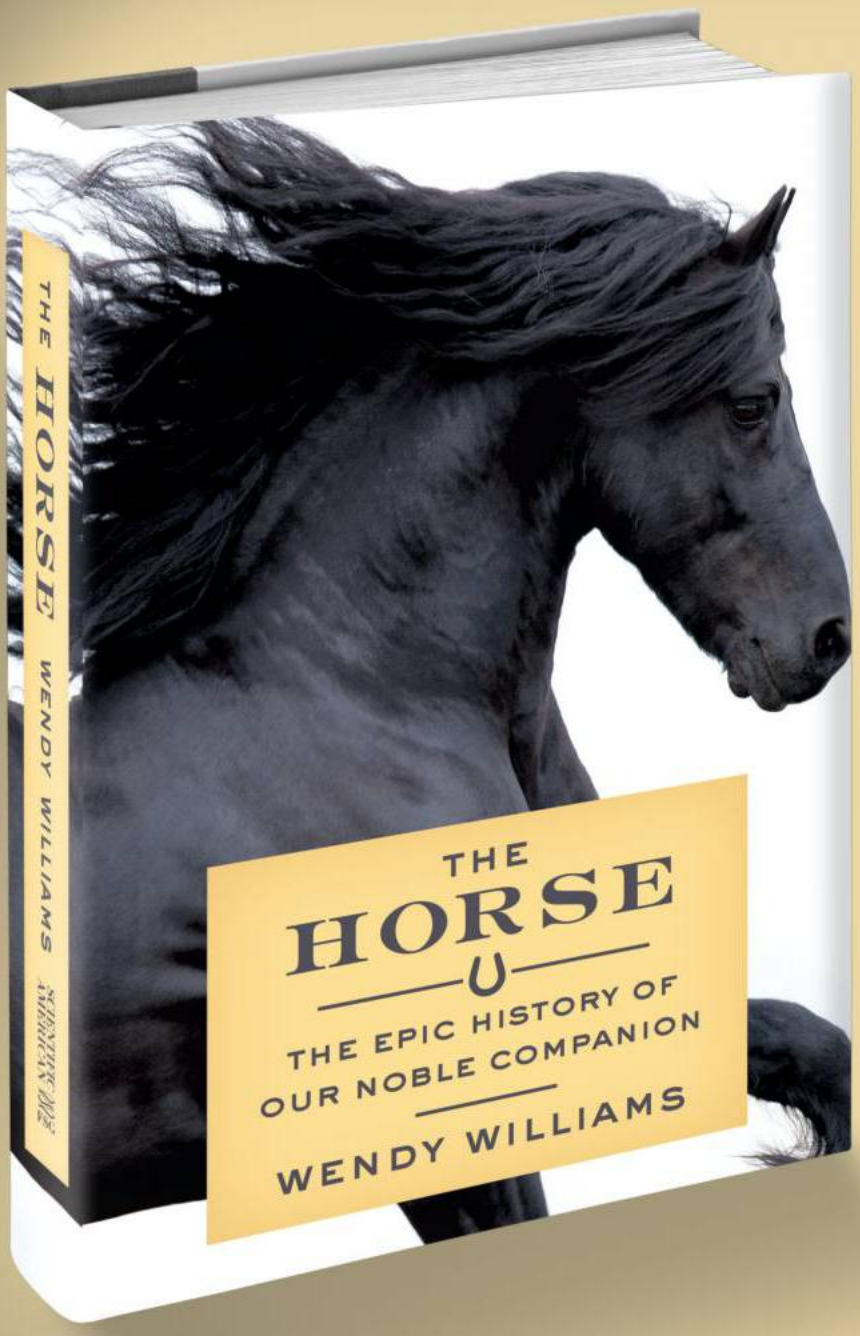

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SCIENCE MATTERS

Alzheimer's disease (*bottom*) destroys neurons in many areas of the brain, including those responsible for memory.

MAGGIE STEBER *Getty Images*

INSIDE

NEUROSCIENCE

The Great Brain Drain

Is a chain reaction of toxic proteins behind all neurodegenerative diseases?

In the human form of mad cow disease, called Creutzfeldt-Jakob, a person's brain deteriorates—literally developing holes that cause rapidly progressing dementia. The condition is fatal within one year in 90 percent of cases. The culprits behind the disease are prions—misfolded proteins that can induce normal proteins around them to also misfold and accumulate. Scientists have known that these self-propagating, pathological proteins cause some rare brain disorders, such as kuru in Papua New Guinea. But growing evidence suggests that prions are at play in many, if not all, neurodegenerative disorders, including Alzheimer's, Huntington's and Parkinson's, also marked by aggregations of malformed proteins.

Until recently, there was no evidence that the abnormal proteins found in people who suffer from these well-known diseases could be transmitted directly from person to person. The tenor of that discussion suddenly changed this September when newly published research in

the journal *Nature* provided the first hint such human-to-human transmission may be possible. (*Scientific American* is part of Springer Nature.)

For the study, John Collinge, a neurologist at University College London, and his colleagues conducted autopsies on eight patients who died between the ages of 36 and 51 from Creutzfeldt-Jakob. All the subjects had acquired the disease after treatment with growth hormone later found to be contaminated with prions. The surprise came when the researchers discovered that six of the brains also bore telltale signs of Alzheimer's—in the form of clumps of beta-amyloid proteins, diagnostic for the disease—even though the patients should have been too young to exhibit such symptoms.

These observations suggest that the tainted hormone injections might have carried small amounts of beta-amyloid proteins that triggered the formation of more such proteins. Neither Alzheimer's nor any known human prion diseases are contagious through direct contact. Yet human transmission of prion diseases has occurred through certain medical procedures and, in the case of kuru, cannibalism. The new study therefore raises the possibility that Alzheimer's is a transmissible disease with an etiology akin to prion diseases.

The new finding is provocative, but experts advise caution in interpreting the results. For instance, neuroscientist John Trojanowski of the University of Pennsylvania points to the small size of the study and lack of direct evidence for transmission in support of causality. But if it is eventually shown that Alzheimer's and other neurodegenerative diseases indeed share the same basic pathological pathway and mechanism, treatments could target one and all.

"Transmission may occur in only a small percentage of human cases," says Claudio Soto, a professor of neurology at the University of Texas Health Science Center at Houston. "But the underlying principle is the most important thing that could lead to new opportunities for therapeutic interventions and diagnostics." Investigators such as Soto and Collinge are working on ways to detect in body fluids the presence of small clumps of the transmissible proteins now thought to be involved in Alzheimer's and other neurodegenerative diseases, which could represent a diagnostic advance.

Such detection will likely be difficult. A study published online in September in the journal *Nature Neuroscience* by Mathias Jucker of the University of Tübingen in Germany and his colleagues required extremely sensitive methods to find minuscule clumps of beta-amyloid proteins, referred to as seeds, in mice brains. These seeds appear to be able to regain pathological properties even after six months of lying dormant. These possibly prionlike proteins might therefore exist in the brain long before symptoms develop, at levels too low to be found by routine tests.

One potentially prionlike protein may cause several diseases, according to a study published this summer by Nobel laureate Stanley Prusiner, who discovered prions in the 1980s. Prusiner and his colleagues found that a "strain" of alpha-synuclein—the misfolded protein involved in Parkinson's—can cause a similar but rare neurodegenerative disease, called multiple-system atrophy. Understanding how variants of these disease-causing proteins differ in shape and how the particular configuration influences their pathogenic nature is destined to become a focus of future research. "There's evidence that both prions and beta-amyloid exist as different strains and have very different biological effects," says Lary C. Walker of Emory University, who was involved in the *Nature Neuroscience* study. "I think understanding this will give us insight into what's happening in disease."

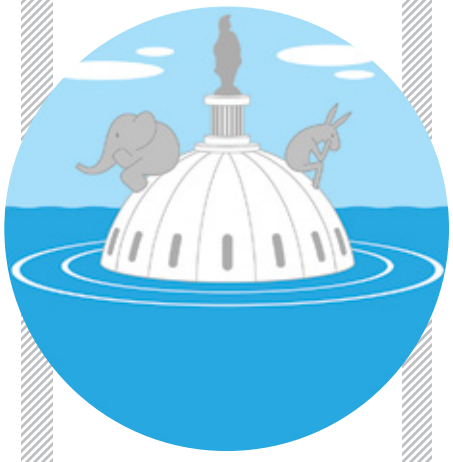
As the evidence increases, more scientists now suspect that prionlike processes probably underlie all neurodegenerative disorders. Prusiner expected the current change in thinking: in his 1997 Nobel Prize lecture, he predicted that the understanding of prion formation could "open new approaches to deciphering the causes of and to developing effective therapies for the more common neurodegenerative diseases, including Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis (ALS)."

—Diana Kwon

BY THE NUMBERS

Both Democrats and Republicans Losing Ground

The nation's capital has sunk to new levels. In fact, Washington, D.C., along with the rest of the Chesapeake Bay area, is losing elevation every day, according to a new study. Prehistoric ice sheets to the north used to push up the mid-Atlantic region indirectly. When they retreated about 20,000 ago, the ground began to settle, and that subsidence will continue for tens of thousands of years, say geologists at the University of Vermont and their colleagues. The combination of descending land and rising sea levels caused by global warming means an inundated White House is closer than previously thought. *—Kat Long*



3.4 millimeters
Average sea-level rise in the Chesapeake Bay region per year (twice that of the global average).

1.3–1.7 millimeters
Annual subsidence of the area.

15 centimeters
Total depth by which D.C. could sink by 2100.

SOURCE: "PLEISTOCENE RELATIVE SEA LEVELS IN THE CHESAPEAKE BAY REGION AND THEIR IMPLICATIONS FOR THE NEXT CENTURY," BY BENJAMIN D. DEJONG ET AL., IN *GSA TODAY*, VOL. 25, NO. 8; AUGUST 2015

Illustrations by Thomas Fuchs

ANIMAL BEHAVIOR

Over-the-Counter Monkey Meds

Red colobus monkeys may eat bark to heal their ills

CARLO BAVAGNOLI *Getty Images*

When a monkey has the sniffles or a headache, it doesn't have the luxury of popping a few painkillers from the medicine cabinet. So how does it deal with the common colds and coughs of the wildlife world?

University of Georgia ecologist Ria R. Ghai and her colleagues observed a troop of more than 100 red colobus monkeys in Uganda's Kibale National Park for four years to figure out whether the rain forest provides a Tylenol equivalent.

Monkeys infected with a whipworm parasite were found to spend more time resting and less time moving, grooming and having sex. The infected monkeys also ate twice as much tree bark as their healthy counterparts even though they kept the same feeding schedules. The findings were published in September in the journal *Proceedings of the Royal Society B.*

The fibrous snack could help literally sweep the intestinal intruder out of the simians' gastrointestinal tracts, but Ghai suspects a more convincing reason. Seven of the nine species of trees and shrubs preferred by sick monkeys have known pharmacological properties, such as antisepsis and analgesia. Thus, the monkeys could have been self-medicating, although she cannot rule out other possibilities. The sick individuals were, however, using the very same plants that local people use to treat illnesses, including infection by whipworm parasites. And that "just doesn't seem like a coincidence," Ghai says. *—Jason G. Goldman*

POISON THAT PURIFIES

University of Helsinki researchers recently announced the first evidence of self-medication in ants. When the biologists exposed hundreds of *Formica fusca* ants to a dangerous fungus, many of the infected insects chose to consume a 4 to 6 percent hydrogen peroxide solution made available for the experiment. Healthy ants avoided the household chemical, which can quash infections in small doses but is otherwise deadly. The sick ants that partook were less likely to succumb to the grips of the fungus. In the wild, they could perhaps acquire the compound by eating plants that release it to fight aphid infestations. *—J.G.G.*

Icebreakers are becoming a more common sight at the top of the world. Soon, cargo ships will be, too.

HUBERTUS KANUS *Science Source*

ENVIRONMENT

A Sooty North Pole Ahead

Less ice will bring more drilling, more shipping—and even more melting

Where there's oil, there's a way. This summer the federal government showed that it is willing to approve drilling operations in U.S. waters off Alaska. In addition to legislation, other barriers to Arctic development are disappearing: summers at the North Pole could be ice-free as soon as 2020, reducing the need for ice-breaking vessels and opening the way for faster and cheaper trading routes. An increase in shipping across the top of the world, however, could have "significant regional impacts by accelerating ice melt," according to a recent government report by the Canadian Northwest Territories. And that aggravated melting could raise global sea levels.

Cargo ships on trans-Arctic voyages and other unprotected international waters typically take advantage of lax regulations and rely on some of the dirtiest fuel. Burning so-called heavy fuel oil is cheap but inefficient, and during the process some of the unburned fuel emerges as soot. Soot may be second only to carbon dioxide as a climate-changing agent: it bolsters the greenhouse effect by trapping more heat in air.

Researchers speculate that the Arctic's environment could amplify soot's negative effects. The substance darkens snow and sea ice, which may then absorb more solar radiation. As sea ice melts, larger swaths

COMMENT AT ScientificAmerican.com/nov2015

Cargo ships on trans-Arctic voyages and other unprotected international waters typically take advantage of lax regulations and rely on some of the dirtiest fuel.

of water are left exposed and thereby soak up even more sunlight. The cycle could continue because the open sea would likely encourage additional soot-emitting shipping.

At best, attempts to quantify shipping's soot emissions are nascent but so are regional-scale studies of soot's environmental impact. "I think the biggest bottleneck is just that the Arctic is awfully big, and there are not a lot of people there and not a lot of measurements," says geochemist Jack E. Dibb of the University of New Hampshire. Dibb and others are working to collect information about the thermal effect of soot on ice cover. Along those lines, researchers in Finland sprinkled several concentrations of black carbon, a component of soot, on snow there from 2011 to 2013 and measured snowmelt over the course of each season. At press time, their results were under review at the journal *The Cryosphere*.

Political leaders are aware of the emerging problem of soot emissions from ships as well as from drilling operations, factories and wildfires. Shortly after approving the Alaskan drilling, President Barack Obama made a visit to the Arctic Circle to draw attention to climate change and melting ice there. His visit coincided with an international summit on Arctic issues whose attendees issued a statement noting the threat that soot poses to the Arctic and the importance of emissions reductions. Dibb and others say they hope that their work persuades politicians to take fast action against soot. If they do, as other climate researchers argued this summer in *Nature Climate Change*, policy makers stand a more credible chance of taking on larger problems, such as the more massive burden of carbon dioxide that is polluting many of the planet's habitats and ecosystems. —*Lucas Laursen*

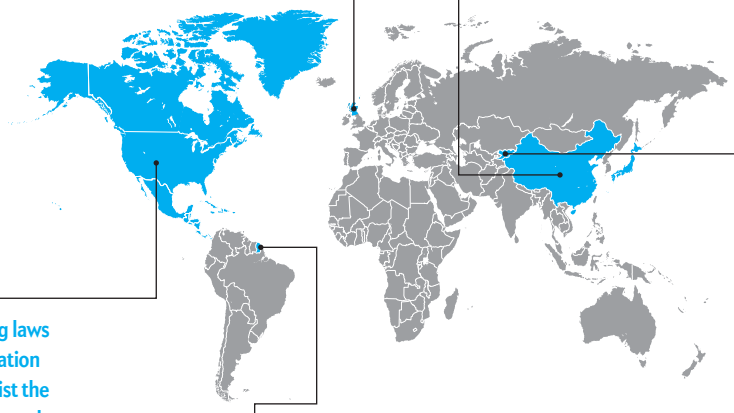
IN THE NEWS

Quick Hits

SCOTLAND
The government announced it will formally ban growing genetically modified crops in the country—counter to England's plan to embrace GMOs. The foods have been approved as safe by the European Union.

CHINA
The People's Liberation Army has trained male macaques to search and destroy birds' nests near military airfields in northern China. The operation prevents damage to aircraft, which can suck the feathery creatures into their engines, the government says. Many ornithologists, however, argue that the method will jeopardize the avian species in the long run.

NORTH AMERICA
Fossil evidence suggests that the arrival of big cats on the continent millions of years ago played a part in the extinction of several canine species—the result of competing for the same prey.



U.S.
Beginning this month, new labeling laws from the Food and Drug Administration require large restaurant chains to list the calorie count in alcoholic drinks. The rules apply only to drinks listed on the menu.

KYRGYZSTAN
Glaciers along Central Asia's largest mountain range, the Tien Shan, have lost 27 percent of their mass and 18 percent of their area in the past 50 years. The meltwater is a major source of freshwater for at least three nearby countries, raising the possibility of future drought.

FRENCH GUIANA
This month the European Space Agency launches a prototype of a space-based detector for gravitational waves, ripples in the curvature of spacetime.

For more details, visit
www.ScientificAmerican.com/nov2015/advances

PUBLIC HEALTH

Fake Weed, Real Crisis

Synthetic cannabinoids are cheap, widespread, hard to track and highly toxic

When powerful street drugs collectively known as synthetic pot are smoked, the resulting high mimics the effects of marijuana. Yet these man-made cannabinoids are not marijuana at all. The drugs, more commonly called spice, fake weed or K2, are made up of any number of dried, shredded plants sprayed with chemicals that live in a murky legality zone. They are highly dangerous—and their use is on the rise.

Synthetic pot, which first hit the market in the early 2000s, has especially caught the attention of public health officials in the past couple of years, stemming from a surge in hospitalizations and violent episodes. Although the drugs act on the same brain pathway as weed's active ingredient, they can trigger harsher reactions, including heart attacks, strokes, kidney damage and delusions. Between June and early August usage of these drugs led to roughly 2,300 emergency room visits in New York State alone. Nationwide more than 6,000 incidents involving spice have been reported to U.S. poison-control centers this year—about double the number of calls in 2013.

Ever changing recipes make it possible for spice sellers to elude the authorities. Each time an ingredient is banned, producers swap in another compound. The drugs are then sold on the Internet or at gas stations and convenience stores at prices lower than genuine marijuana. The changing formulations also pose a challenge for researchers trying to match the chemicals with their side effects or to develop tests to identify them in a user's system. "The drugs are present in blood for only a short period, so it's very difficult to detect them," says Marilyn Huestis, chief of the Chemistry and Drug Metabolism Section at the National Institute on Drug Abuse. Huestis is now working to identify synthetic cannabinoid by-products via a method that captures all ions present in a single test sample. It can take a month to evaluate one compound, but to keep up with the influx of pot knockoffs, she says, "I think this [method] is our only hope." —*Dina Fine Maron*

GETTY IMAGES

The antisubmarine MK-50 torpedo relies on SCEPS for power.

SPACE

A Partner for Plutonium

NASA eyes torpedo tech as an alternative to nuclear batteries

Until recently, NASA faced a severe plutonium shortage that jeopardized future deep-space missions. In 2013 the U.S. Department of Energy announced, after a 25-year pause, that it would restart production of plutonium 238—the backbone of long-lasting nuclear batteries that have powered numerous missions since 1969. Yet the damage from the hiatus was already done. By 2021 the new effort will yield only enough of the radioactive fuel to make about two and a half nuclear battery modules a year. (The Mars rover Curiosity alone needed eight modules.) This paucity, plus the small existing stockpile, is barely adequate for the next decade of planned planetary missions to destinations such as the icy moons of Jupiter and Saturn. So NASA has been investigating alternatives. It recently become interested in a seafaring candidate: a military technology that has propelled U.S. Navy torpedoes.

The navy first experimented with Stored Chemical Energy Power Systems (SCEPS) in the 1920s, but it was not until the 1980s that engineers at Pennsylvania State University adapted the technology for warheads that could go fast enough and deep enough in their hunt for Soviet submarines. SCEPS harnesses the chemical reaction of two energy-dense reactants that remain stored and separated until needed. In torpedoes, the system commonly holds its energy in reserve as a solid block of lithium and a tank of the inert gas sulfur hexafluoride. When triggered, the combustion reaction of the two materials creates heat that turns the weapon's steam turbine to produce thousands of kilowatts of power.

The NASA version would tweak that chemical recipe. Michael Paul, a space systems engineer at Penn State, has proposed a demonstration mission to Venus, where a SCEPS-enabled robotic lander would draw on the planet's atmospheric carbon dioxide to burn the lithium. The resulting heat could drive an electrical generator to produce about three lightbulbs' worth of power, a sizable budget for space missions. (The Mars rovers Spirit and Opportunity ran on about one lightbulb's worth of solar power.) In July, Paul received half a million dollars in funding through the NASA Innovative Advanced Concepts program to measure the exact efficiency of carbon dioxide and lithium in this configuration. He will also work with planetary scientists to make recommendations to the space agency about other mission applications.

Nuclear power remains irreplaceable for deep-space missions intended to operate for years or decades, as Voyager, Cassini and New Horizons have done to much success, says Ralph McNutt, a physicist at the Johns Hopkins University Applied Physics Laboratory and chair of a NASA report this July on the available U.S. plutonium supply. Yet McNutt describes SCEPS as "exciting stuff."

If Paul's vision comes to fruition, the energy from SCEPS could enhance missions using nuclear batteries or support those on trajectories too far from the sun to rely on solar power. Such technology might someday propel rovers designed to explore permanently shaded craters on the moon, run a Mars lander's drill in a dimly lit region or generate heat to keep a robot's electronics warm on icy Europa. SCEPS could even provide all the muscle behind shorter missions to not too distant destinations that would last days or weeks rather than years. —*Jeremy Hsu*

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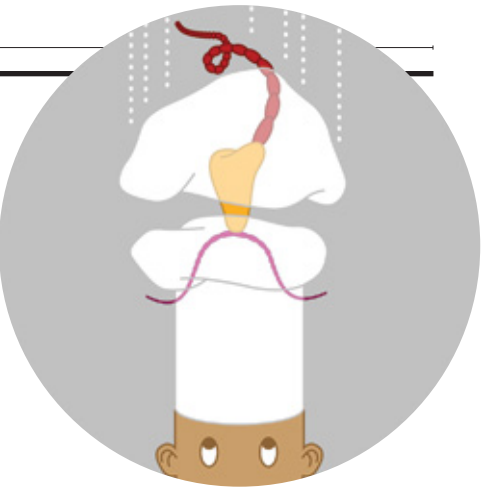
COMMENT AT ScientificAmerican.com/nov2015

BIOTECHNOLOGY

New Cook Arrives in Life's Kitchen

Synthetic cells get one step closer to reality



Inside every cell is a chef of sorts, cooking up the "cuisine" that makes life possible—a vast array of proteins. Now scientists have built an alien chef, capable of cooking from recipes written in artificial DNA to make novel proteins that might serve as antibiotics, biofuels or other useful molecules.

In the typical order of things, these chefs, known as ribosomes, are made of two pieces of RNA and amino acids that work together briefly to build proteins and then go their own ways when the job is done. Biological engineer Michael Jewett of Northwestern University and pharmaceutical biotechnologist Alexander Mankin of the University of Illinois at Chicago decided to try something new: tethering the two parts of their synthetic ribosome, Ribo-T, to each other so it could continue to follow the same set of novel instructions. No prior life on earth—either evolved in the wild or made by scientists in the laboratory—is known to have ever had or lived with such a tied-up ribosome.

This new chef cooks just fine, however. Ribo-T successfully built green, fluorescing proteins. And *Escherichia coli* with only the synthetic ribosomes lived nearly as well as wild peers. Further, the *E. coli* passed Ribo-T on to its offspring. "This alien will help us better understand how normal ribosomes work," Mankin says.

In fact, this study reveals something heretofore unknown: ribosomes do not have to be promiscuous to work—the two units that usually combine and separate can be tethered together permanently without killing the cell. Plus, the alien ribosome and a more typical one can work side by side, one cooking up the unique proteins while the other churns out the enzymes necessary to keep the cell alive. DARPA supported the work as part of the agency's effort to craft living foundries for new materials, whether medicinal molecules or better biofuels.

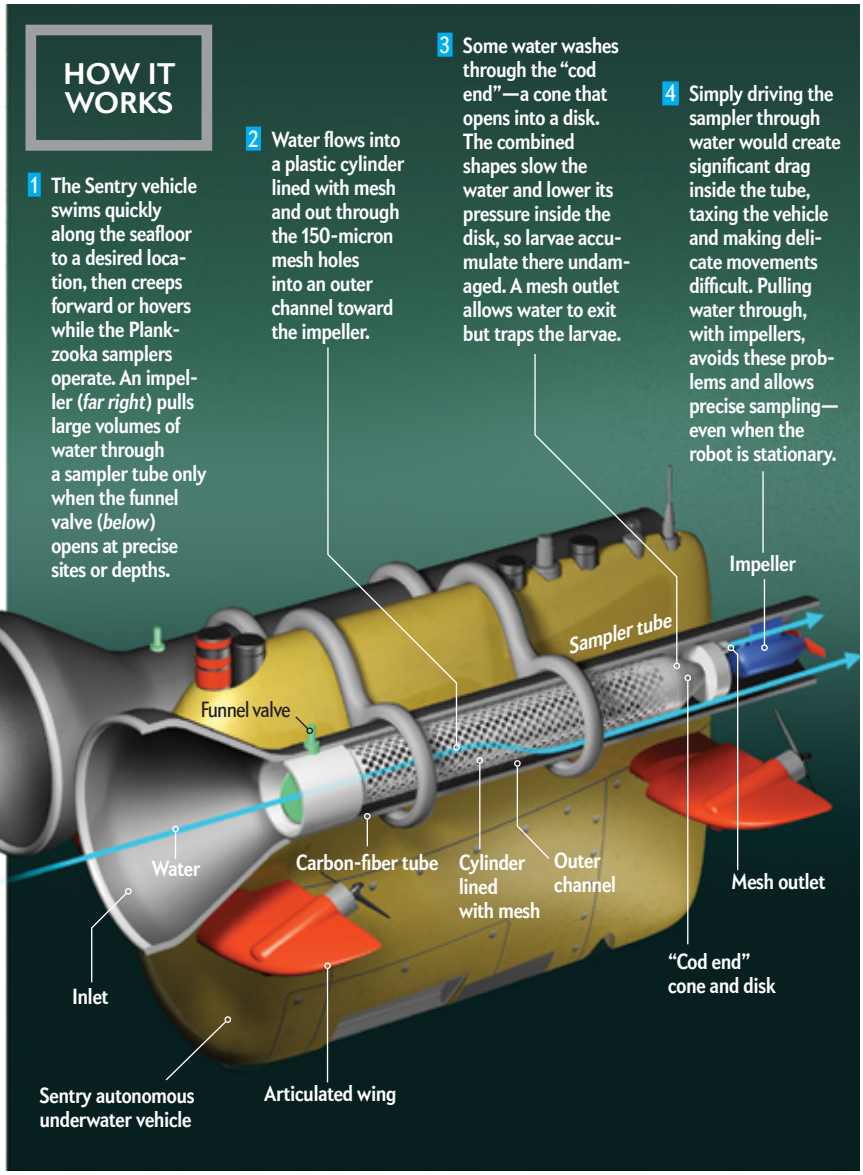
Base pairs that exist only in the lab, rearranged chromosomes, even entire synthetic genomes—all have been made by scientists in recent years. Now add to the synthetic biologist's toolbox a new ribosome, a designer chef that can cook up new dishes with de novo ingredients such as "unnatural" amino acids. Bon appétit. —*David Biello*

ROBOTICS

Deep-Sea Sampler

A nimble robot captures a marvelous array of tiny creatures

Oceanographers can learn a lot about marine food webs and chemical vents at the bottom of the ocean by analyzing the larvae of tiny plankton that live along the seafloor. But moving a robot vehicle to precise spots along the pitch-black, irregular surface is difficult. So is sifting through large volumes of water to snag the fragile critters, barely visible in size, without tearing them apart. In July the Sentry autonomous underwater vehicle took a new sampler, called SyPRID, to six methane seeps in the Atlantic Ocean between North Carolina and Nantucket, in some cases more than 2,000 meters down. SyPRID, nicknamed Plankzooka for its bazooka rocket-launcher shape, retrieved 132 distinct species. The precision sampling, says Carl Kaiser, vehicle program manager at the Woods Hole Oceanographic Institution, "will allow scientists to analyze the difference between larvae at 2.5 meters from the bottom versus five meters or, say, 10 meters away from a vent versus 50—great comparative studies." —*Mark Fischetti*



ASTRONOMY

Gone without a Bang

Disappearing stars in nearby galaxies may reveal the births of black holes

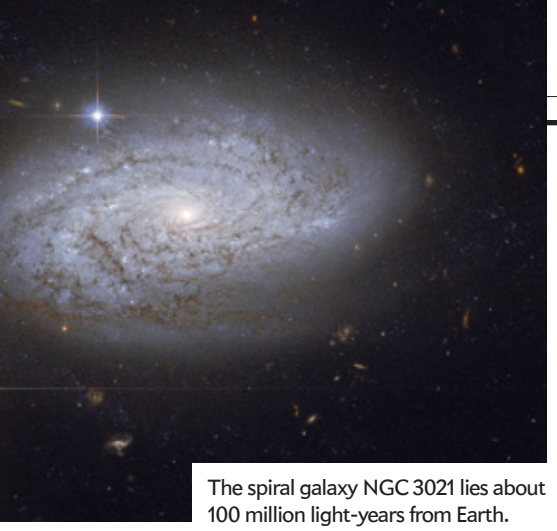
In the classic Sherlock Holmes story "Silver Blaze," the famed detective solves a murder mystery by noticing something that does *not* happen: a watchdog's failure to bark in the middle of the night. Astronomers are now using a similar inference to solve the cosmic mystery of a black hole's birth—looking for stars that fail to explode.

Stars many times more massive than our sun often end their lives with a supernova, a cataclysmic explosion caused by the collapse of the star's heavy core. Because they are so bright, supernovae across the universe can be observed and studied here on Earth. Modern astronomers have yet to see one in our Milky Way but have managed to witness a few dozen in nearby galaxies with known progenitor stars. Strangely, though, none of those stars was bigger than about 17 solar masses, even though much more massive stars abound and should also be dying as supernovae.

Theorists suspect black holes could explain this curious observation. When the cores of certain "red supergiant" stars collapse, instead of making supernovae, they may form black holes that simply swallow up the disintegrating star. Seen from afar, the disappearance of the star could then announce the birth of a new black hole. "We call these 'failed supernovae,'" says Stan Woosley,

COURTESY OF ADAM RIESS *Space Telescope Science Institute*, NASA AND ESA (*galaxy*)

Illustration by Don Foley



The spiral galaxy NGC 3021 lies about 100 million light-years from Earth.

an astrophysicist at the University of California, Santa Cruz, who has modeled the process. "Now you see a red supergiant. Now you don't."

In 2008 Chris Kochanek and his colleagues at Ohio State University proposed a way to search for these elusive deaths. Unlike most supernovae surveys, which look for bright bursts of light, Kochanek would monitor about 30 nearby galaxies for curious patches of darkness where a star had suddenly disappeared. Last year, based on observations with the Large Binocular Telescope Observatory in Arizona, Kochanek and his colleagues Jill Gerke and Kris Stanek announced their discovery of one convincing failed supernova candidate, a red supergiant in the galaxy NGC 6946 that briefly flared and then seemed to wink out of existence.

Now there are two possible sightings of black hole births. In July, Thomas Reynolds, Morgan Fraser and Gerard Gilmore, all at the University of Cambridge, reported they had seen another supergiant fade to black amid a star cluster in archival Hubble Space Telescope observations of the galaxy NGC 3021. The results from both teams were published in separate papers in the *Monthly Notices of the Royal Astronomical Society.*

Certainly there are more prosaic explanations for both candidates: the stars could be variable and wildly fluctuating in brightness, or they might have drifted behind clouds of dust. The research teams plan more in-depth observations with space telescopes to strengthen the case for the dark births of black holes.

Among the best sights they could see would be nothing at all. "Death has a special property that other sources of stellar variability do not," Kochanek says. "Death is forever." If the stars reappear, Fraser says, "then they clearly haven't exploded," and the search for failed supernovae will go on or fade away. —*Lee Billings*

COURTESY OF EDMUND SUMNER (*bridges*)

ENGINEERING

Super Fan

Inspired by a Japanese folding fan, Merchant Square Footbridge in Paddington, London, gracefully opens above a historical canal at least once a week to allow small boats to pass. It was completed last year, and its unique design is a 2015 finalist for a prestigious award from the Institution of Structural Engineers. The organization annually honors creativity and technical advancement in projects throughout the world.

In an engineering first, the bridge's architects designed the slats of the fabricated steel span into a cascade of cantilevers. Each of the five beams has a dedicated concrete counterweight and pivot mechanism; hydraulic cylinders below the pivots, combined with the counterweights, enable them to lift in sequence with minimal effort. When opened, the tallest beam extends like the top rib of a hand fan to nearly vertical, and the lowest rises 2.5 meters above the canal—high enough for small craft to pass underneath. "The fingers can rise and fall at different speeds and to different inclinations—all very innovative," says Ian Firth, one of the judges of the awards, which will be announced this month.

A simpler structure could have sufficed to provide pedestrian passage across the water. This bridge, however, stands as a work of art, Firth adds, combining form and function in one dazzling display. —*Kat Long*

STRUCTURAL DESIGNERS
Knight Architects and AKT II

LENGTH
20 meters

WIDTH
3 meters

RAISE/LOWER DURATION
3 minutes

STEEPEST ANGLE WHEN OPEN
80 degrees

Ellen Ruppel Shell is author, most recently, of *Cheap: The High Cost of Discount Culture* and is co-director of the Graduate Program in Science Journalism at Boston University.

Overreaction

Many children are wrongly diagnosed with food allergies because of inaccurate tests

By Ellen Ruppel Shell

Just a few years ago a 15-month-old girl—her stomach, arms and legs swollen and her hands and feet crusted in weeping, yellow scales—was rushed to the emergency room at the University of Texas Southwestern Medical Center in Dallas. Laboratory tests indicated a host of nutrition problems.

The child's mother, during the previous year, had told doctors that standard infant formula seemed to provoke vomiting and a rash. The mother and her pediatrician assumed the girl was allergic to the formula and switched her to goat's milk. Symptoms persisted, though, and the baby was switched again, to coconut milk and rice syrup. At 13 months, the pediatrician noted yet another red, swollen rash and ordered an allergy test, the child's first. The test identified coconut as a so-called high-reaction class, and coconut milk was removed from her diet. Reduced to a diet of rice milk, the child's symptoms worsened.

In the ER, doctors determined the girl suffered from kwashiorkor, a nutritional disorder rarely seen in the developed world. She was fed intravenously and evaluated by a team that included pediatric allergist J. Andrew Bird, who used more sophisticated methods to test her response to coconut and cow's milk, wheat, soy, egg white, fish, shrimp, green beans and potatoes. To her mother's astonishment, the toddler showed no adverse reaction to any of them. After a few days of steady nourishment and a course of antibiotics to clear her skin of various infections, she was released from the hospital into a life free of food restrictions. (Her digestive upsets appeared to be caused by a variety of common ailments that would have almost certainly cleared on their own.)

The problem was not in the baby but in the tests. Common skin-prick tests, in which a person is scratched by a needle coated with proteins from a suspect food, produce signs of irritation 50 to 60 percent of the time even when the person is not actually allergic. "When you apply the wrong test, as was the case here, you end up with false positives," says Bird, who co-authored a paper describing the Dallas case in 2013 in the journal *Pediatrics*. And you end up with a lot of people scared to eat foods that would do them no harm. Bird has said that he and a team of researchers found that 112 of 126 children who were diagnosed with multiple food allergies tolerated at least one of the foods they were cautioned might kill them.

Kari Nadeau, director of the Sean N. Parker Center for Allergy Research at Stanford University, says that many pediatricians and family physicians are not aware of these testing flaws. "When it comes to diagnosis, we've been in the same place for about 20 years," she observes. To move forward, Nadeau and other researchers are developing more advanced and easily used methods.

Food allergies are real and can be deadly, but mistakenly slapping an allergy label on a patient can be a big problem as well. First, it does not solve the person's troubles. Second, a diagnosis of allergies comes with a high price: a few years ago Ruchi S. Gupta, a pediatric allergist affiliated with the Northwestern University Feinberg School of Medicine, estimated the annual cost of food allergy at nearly $25 billion, or roughly $4,184 per child, with some of that attributed to medical costs but even more to a decline in parents' work productivity.

There is a mental health price as well: children who believe they have a food allergy tend to report higher levels of stress and anxiety, as do their parents. Every sleepover, picnic and airplane ride comes fraught with worry that one's child is just a peanut away from an emergency room visit or worse. Parents and children must be ever armed with an injectable medicine that can stave off a severe allergic reaction. The prospect of a

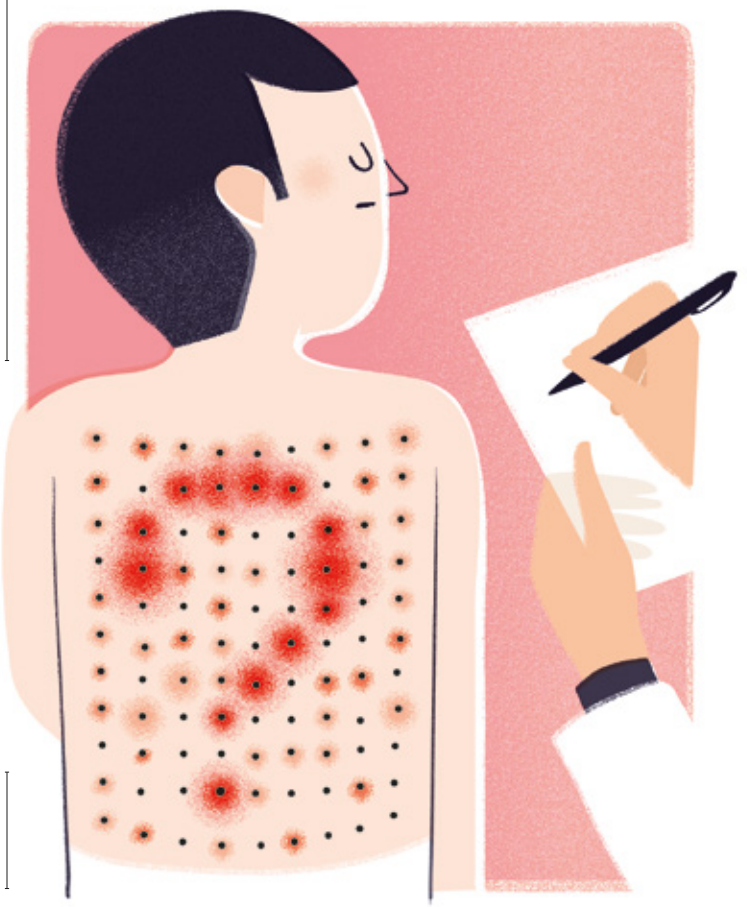


Illustration by Marie Mainguy

lifetime of this vigilance can weigh heavily on parents, some of whom go so far as to buy peanut-sniffing dogs or to homeschool their children to protect them both from exposure to the offending food and from the stigmatization of the allergy itself.

Pediatric allergist John Lee, director of the Food Allergy Program at Boston Children's Hospital, has heard more than his share of horror stories. "Food allergies can be terribly isolating for a kid," he says. "One parent told me his child was forced to sit all alone on a stage during lunch period. And siblings can feel resentful because in many cases parents don't feel they can take family vacations or even eat dinner in a restaurant."

Diagnosing a food allergy usually begins with a patient history and the skin-prick test. If the scratch does not provoke a raised bump surrounded by a circle of red itchiness, the patient almost certainly is not allergic to the material. But positive tests can be harder to interpret because skin irritation does not necessarily reflect a true allergy, which is a hypersensitivity of the immune system that extends through the body. In a real allergy, immune components such as IgE antibodies in the blood are stimulated by an allergen. The antibody binds to immune cells called mast cells, which then triggers release of a cascade of chemicals that produce all kinds of inflammation and irritation. But levels of allergen-specific antibodies in the blood are quite low even in allergic people, so running a simple blood test is not an answer, either.

The diagnostic "gold standard" for food allergy is a placebo-controlled test. A potential irritant is eaten, and the body's response (a rash, say, or swelling) is compared with what happens after eating something that looks like the irritant but is benign. For example, a patient who might be allergic to eggs is given a tiny amount of egg baked into a cake, along with a taste of egg-free cake. Ideally, the test is double-blind, meaning that neither the patient nor the allergist knows which cake contains egg. The accuracy rate of these tests, for both positive and negative results, is about 95 percent, according to Lee.

Unfortunately, this procedure is tricky, time-consuming, expensive and relatively uncommon; experts agree that few allergy sufferers have access to it.

James Baker, who is a physician and immunologist and CEO of the nonprofit Food Allergy Research & Education (FARE), says his organization is tackling this problem by setting up 40 centers around the country to administer food challenges with all the necessary precautions. "You have to be prepared to treat or transport people to the emergency room if they react," he asserts.

Scientists are also looking for something easier to use. One promising newcomer to the diagnostic arsenal is the basophil-activation test (BAT). Basophils, a type of white blood cell, excrete histamines and other inflammatory chemicals in reaction to a perceived threat—such as an allergen. Nadeau and her colleagues have designed and patented a test that involves mixing just one drop of blood with the potential allergen and measuring the reaction in basophils. In pilot studies, the procedure diagnosed allergies with 95 percent accuracy in both children and adults, a rate similar to that of food-challenge tests.

BAT is still in the research phase and requires more studies with a larger, more varied population, but another approach—allergen-component testing—has already been approved by the U.S. Food and Drug Administration for peanut allergies. Lynda Schneider, a pediatric allergist and director of the Allergy Program at Boston Children's Hospital, says that some children have a mild sensitivity—but not a full-blown allergy—to one protein in peanuts. Rather than testing them with crude mixtures of lots of proteins found in nuts, Schneider's component tests isolate specific proteins and then challenge the patient with those. By sorting out which protein is prompting the negative reaction, physicians can determine with a high degree of accuracy whether the patient is truly allergic to peanuts.

Schneider wants to get beyond diagnosis and into treatment. Omalizumab is a monoclonal antibody that binds to IgE antibodies and prevents them from glomming on to mast cells, which triggers the allergic cascade. In a recent study, Schneider and her colleagues administered this so-called anti-IgE drug over the course of 20 weeks to 13 children who were known to have peanut allergies while giving them a gradually larger dose of peanuts. During the anti-IgE phase, none of the children developed an allergic reaction to peanuts, although two did have a recurrence once the anti-IgE regime ended. "The anti-IgE allowed their system to go through a desensitization process," Schneider says.

Kids who are allergic to milk and eggs can be gradually desensitized by heating these foods for 30 minutes or so, Bird has found. The heat changes the shape of these proteins, which vastly reduces their tendency to provoke allergies. This is not a home remedy, and it is done under medical supervision, but studies of kids who are fed small amounts of heated egg or milk show the children are far more likely to acquire a tolerance to these foods over time—that is, more likely to outgrow the allergy. A study called Learning Early About Peanut Allergy (LEAP) showed that exposing children to tiny amounts of peanut products early in their life dramatically reduced the incidence of allergy.

Scott H. Sicherer, a professor of pediatrics, allergy and immunology at the Icahn School of Medicine at Mount Sinai, takes the early desensitization idea a step further. He suggests children can best avoid food allergies if they eat a wide variety of foods at an early age, run in the open air and "play in the dirt." A little less protection from the world, he says, may be the best protection from allergies. SA

Most Common Food Allergies in Children

Based on self-reports of symptoms*

Peanuts	2.0%
Milk	1.7%
Shellfish	1.4%
Nuts from trees	1.0%
Eggs	0.8%
Fin fish	0.5%
Strawberries	0.4%
Wheat	0.4%
Soy	0.4%

*SURVEY OF 38,480 CHILDREN

SOURCE: "THE PREVALENCE, SEVERITY, AND DISTRIBUTION OF CHILDHOOD FOOD ALLERGY IN THE UNITED STATES." BY RUCHI S. GUPTA ET AL., IN *PEDIATRICS*. PUBLISHED ONLINE JUNE 20, 2011

SCIENTIFIC AMERICAN ONLINE
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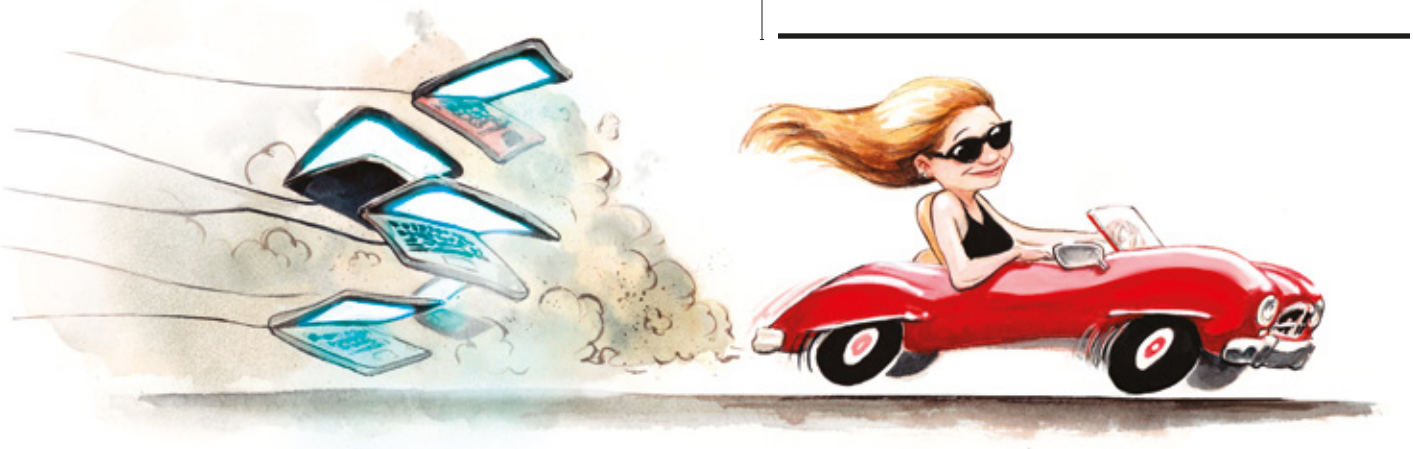
SCIENTIFICAMERICAN.COM/NOV2015

David Pogue is the anchor columnist for Yahoo Tech and host of several *NOVA* miniseries on PBS.



Hackers at the Wheel

Why your car is not about to get crashed by cybercriminals

By David Pogue

As scare-tactic journalism goes, it would be hard to beat this past summer's article about hackers taking remote control of a *Wired* magazine writer's car.

"I was driving 70 mph on the edge of downtown St. Louis," he wrote. "As the two hackers remotely toyed with the air-conditioning, radio, and windshield wipers, I mentally congratulated myself on my courage under pressure. That's when they cut the transmission."

Scary! Hackers can take over our cars! Our lives are at risk!

No, they're not.

Stories such as these are catnip to mainstream media and the technophobic public. Unfortunately, they leave out or underplay a detail or two that would take most of the air out of the drama: these aren't just any cars.

In the case of the *Wired* article, the Jeep belonged to the hackers. They had been working on its software for three years to make it hackable. That one Jeep.

That's really a different story.

In February *60 Minutes* ran a story about a similar experiment. "Oh, my God," the correspondent exclaims as her brakes stop working. "That is frightening!"

But would it have been as frightening if she had mentioned that this kind of hack requires a car with cellular Internet service, that it had taken a team of researchers years to make it work—*and* that by then the automaker had fixed the software to make such a hack impossible for vehicles on the road?

Then this, in August: "Two researchers have found that they could plug their laptop into a network cable behind a Tesla Model S's driver's-side dashboard, start the car with a software command, and drive it," *Wired* reported.

But wouldn't you see that if you were in the driver's seat?

Here's the simple truth. No hacker has ever taken remote control of a stranger's car. Not once. It's extraordinarily difficult to do. It takes teams working full-time to find a way to do it on *one* car model—and requires having physical access to the specific car.

The journalists should also stop calling the perpetrators "hackers." These are researchers—the good guys—not evildoers hiding in bunkers somewhere.

Every time one of those stories pops up, I feel like pulling up alongside the reporters in my own noncellular 2009 Honda Fit and yelling, "Hack this!"

Now let me hasten to say this: car security is serious. Not very many cars have built-in Internet connections today—designed for emergency communication, to bring Internet information to the dashboard or to supply a Wi-Fi signal to passengers in the car—but their number is growing. Researchers' demonstrations have underscored the importance of designing these systems securely—for example, of keeping cars' control circuits separate from the Internet ones.

In other words, the *industry's* concern over hackable cars isn't misplaced. Researchers who try to break in are performing a valuable service in drawing attention to a *potential* danger.

All three cases described here led to prompt software fixes by the carmakers, who are keen to avoid their products seeming vulnerable. None of those researchers would be able to repeat their demonstrations today.

Unfortunately, you haven't read the last "you're a sitting duck" hacker story. Connected cars are only part of the larger "Internet of things" movement, in which more everyday objects are being made capable of getting online. Home door locks, lighting systems, coffee makers—designing all of it with excellent security is extremely important, and there will be occasional failures.

Yes, new technology is always a little scary. But let's not exploit that fear. Let's assess the hackable-car threat with clarity, with nuance—and with all the facts. Today remotely hackable cars are still only a hypothetical threat. It's not one that should keep everyday drivers up at night. SA

SCIENTIFIC AMERICAN ONLINE
HOW CARS GET HACKED:
SCIENTIFICAMERICAN.COM/NOV2015/POGUE

Illustration by Scott Brundage

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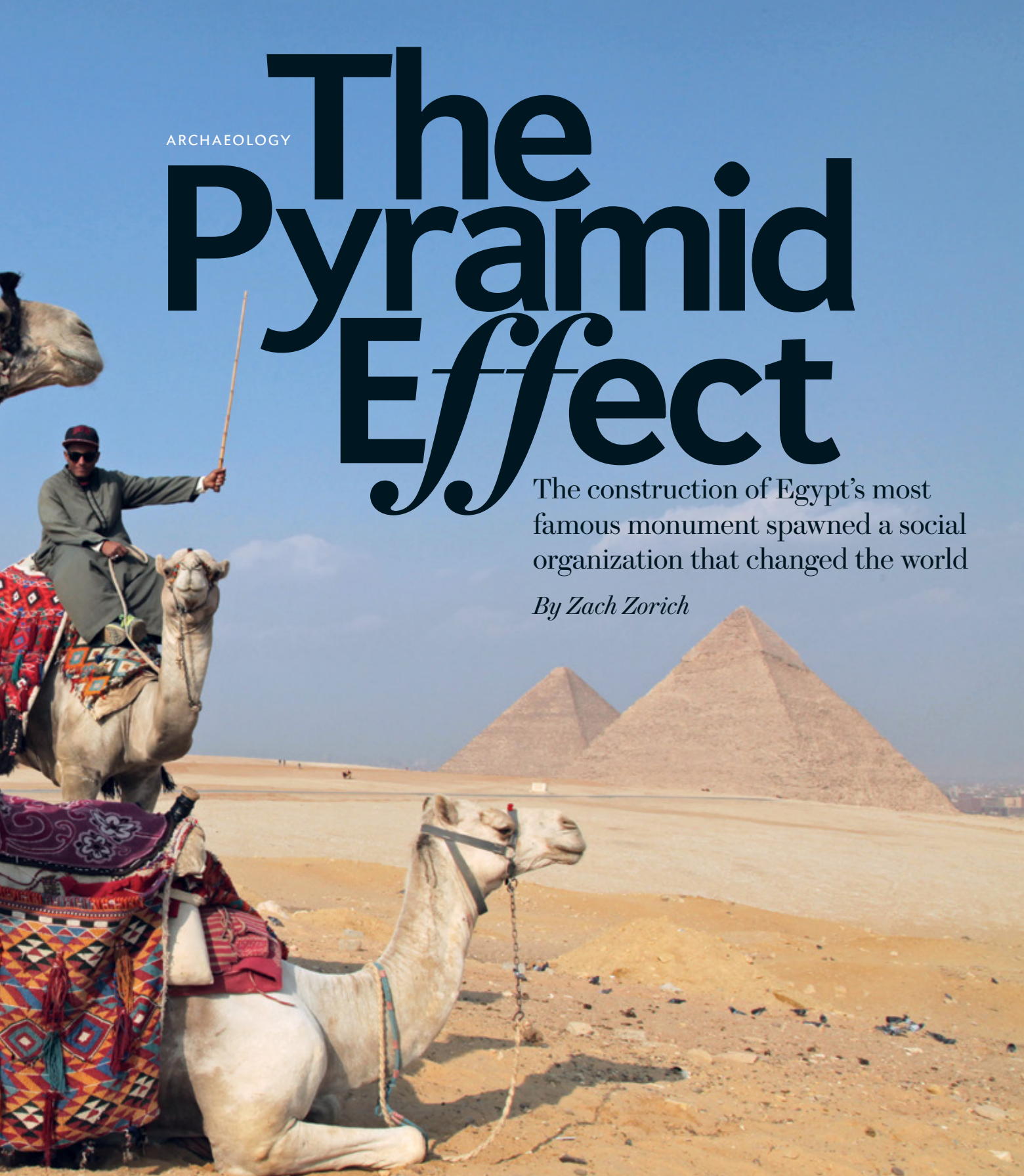
ARCHAEOLOGY

The Pyramid Effect

The construction of Egypt's most famous monument spawned a social organization that changed the world

By Zach Zorich



NEW DISCOVERIES are revealing the people who built the famed monuments of Egypt's Giza Plateau, including the pyramids of Pharaoh Khufu (*left*) and Pharaoh Khafre (*right*).

Photographs by Rena Effendi

Zach Zorich is a Colorado-based freelance writer and a contributing editor to *Archaeology*. His last article for *Scientific American* described the discovery of a major Maya sculpture in Guatemala.

LATE SUMMER IN EGYPT, around 2525 B.C., and the Nile is flooding. To a worker named Merrer, the deluge means it is time to bring stone to the site of Pharaoh Khufu's pyramid. The journey from the quarry in Tura southeast of the port at Giza is just eight miles. But the heavy cargo of gleaming white limestone, which will form the outer layer of the monument, makes the crafts difficult to maneuver. And the river seems as vast as an ocean when it rises over its banks. Merrer has sailed the open seas before, however. The fleet of barges and the 50 men under his command are in experienced hands.

He eyes their destination. In the distance he can see the floodwaters lapping against a massive limestone wall. Other boats carrying grain, lumber and livestock sail around the east end of the wall to unload their cargoes in the town there, but Merrer's barges aren't going that far. They make landfall north of the wall, where the golden bedrock of the Giza Plateau slopes down to the river, forming a natural ramp that will facilitate moving the limestone to the construction site.

From the river's edge, Merrer can see what will be the tallest building in the world for at least the next 3,800 years. Thousands of workers swarm across the construction site of the pyramid, which will eventually serve as Khufu's tomb, hauling the giant stones into position and checking and rechecking their alignment. The structure is nearing completion. Soon the upper layers of stone blocks will be in place, and the pyramid will be fully encased in polished Tura limestone and topped with a gilded capstone.

Who were the people who built Khufu's pyramid and the pyramids of Egypt's other pharaohs, and why did they devote their lives to the task? Greek historian Herodotus, writing in the fifth century B.C., thought that the pyramids had been built by armies of slaves motivated by the whips of their overseers. In the past few decades, however, discoveries of other written sources have shown that gangs of Egyptian citizens provided most of the labor. But these sources revealed next to nothing about the lives of those people. For all archaeologists knew, they could have been low-paid laborers who were treated little better than slaves—half-starved, bedraggled men lashed until the limestone was unloaded from the barges onto wood sledges and dragged up to the pyramid.

Now new findings, including a papyrus ledger that documents the activities of Merrer and his crew, are finally bringing the pyramid workers into focus—and showing the iconic monuments they built in an entirely new light. Excavations at two key sites suggest that the significance of the pyramids reaches far beyond being feats of engineering. It turns out the workers who built these structures did not just drag stone blocks. They were an elite labor force that also sailed trade missions to locales hundreds of miles away to bring back supplies and building materials. The development of the highly sophisticated labor organization and trade network needed to build the pyramids did more than make it possible to construct huge monuments; it set the stage for centuries of Egyptian prosperity and altered the course of later civilizations.

AIMING HIGH

PYRAMID BUILDING DID NOT BEGIN on the Giza Plateau. Pharaoh Netjerikhet, who ruled from 2650 to 2620 B.C., built the first

IN BRIEF

For years archaeologists who study the Giza pyramids in Egypt have focused on the engineering details of these monuments. But the real significance of the pyramids lies in the social organization they gave rise to.

New finds in the ancient city of Heit el-Ghurab near Giza and a contemporaneous Red Sea port known as Wadi el-Jarf are revealing the government, labor and trade infrastructures that the pharaohs developed to get the pyramids, particularly the Great Pyramid, built.

These infrastructures brought Egypt tremendous lasting wealth and enriched the economies of its trading partners.

EXCAVATORS at Heit el-Ghurab, an ancient city near the pyramids, have unearthed traces of the pyramid builders (*left*). Archaeologist Mark Lehner peers into an excavation pit in the livestock corral area (*above*).

such monument, a six-tiered step pyramid some 200 feet tall that still dominates the skyline at Saqqara, about 15 miles south of Giza. The trend of building large pyramids really took off with fourth dynasty Pharaoh Sneferu, who built three pyramids during his reign from 2575 to 2545 B.C. When Sneferu finally passed away, his son Khufu (sometimes known as Cheops) succeeded him. For Khufu, there was only one way to outdo his father: he had to build a bigger pyramid. And he would erect it on the edge of the Giza Plateau for all to see. Khufu's ambition led to the construction of Egypt's most famous monument, the 481-foot-tall, 756-foot-wide Great Pyramid of Giza.

Khufu's striving did not end there. A mortuary temple was built on the east side of the pyramid where priests could communicate with the deceased pharaoh and make offerings to support him in the afterlife. On either side of the temple enormous pits were dug to hold full-sized boats, probably for Khufu to sail in the afterlife. Two more boat pits were dug on the south side of the pyramid. And three smaller pyramids that served as tombs for important royal women stand just south of the mortuary temple. All told, the complex was a colossal undertaking.

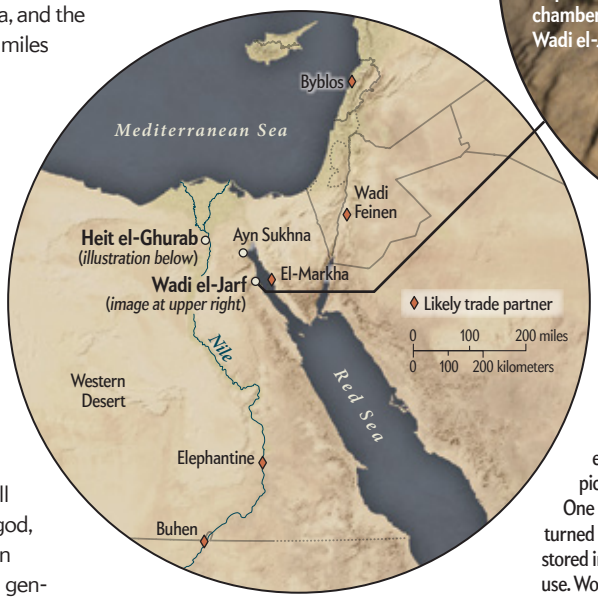
For years archaeologists have obsessed over the engineering of the pyramids. Experts estimate that construction of the Great Pyramid alone would have required about 26,000 people to set the blocks at the bottom of the structure. As the pyramid rose and the surface area at the top diminished, the number of individuals working at the site would have decreased. Theories for how workers moved the hefty stones into place abound. The leading idea holds that they built an internal ramp to cart the limestone to successively higher positions in the structure. But in focusing on practical details of construction, scholars missed the greater importance of the pyramids. Until now.

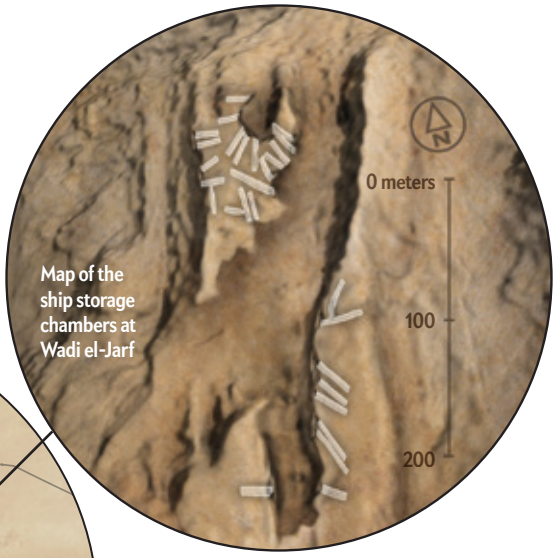
Mark Lehner is shaking hands and exchanging warm Arabic greetings with visitors next to Heit el-Ghurab ("Wall of the Crow")—a 30-foot-tall barrier half a mile east of the Great Pyramid. In Merrer's day, the wall would have stood north of the town, which is also called Heit el-Ghurab. Today, with the river having moved east, Cairo's urban sprawl, rather than Nile floodwater, sloshes up against the wall. When people take photographs of the pyramids, they always turn their backs to this area, preferring the vastness of the open desert to Cairo's unruly skyline. Archaeologists, too, long ignored this place—an expanse of sand wedged between the escarpment of the Giza Plateau and the encroaching city. Lehner, an Egyptologist at the Oriental Institute at the University of Chicago and director of Ancient Egypt Research Associates, based in Massachusetts, began working here in 1988 with a very specific goal in mind. He realized that the mystery of the Giza pyramids is not how so many big stones were cut and stacked; the mystery is the people. "We see the human touch everywhere," he says. "So where are the humans?" He came to Heit el-Ghurab to look for them.

Lehner is equally at home in modern Cairo and ancient Heit el-Ghurab. Today he is dressed for fieldwork in blue jeans, a

A Tomb for a God

Pharaoh Khufu's Great Pyramid was not the first pyramid built in Egypt, but it was the biggest. Its construction, on the edge of the Giza Plateau, required a national effort. Excavations in the ancient city of Heit el-Ghurab, next to Giza, and the one-time port of Wadi el-Jarf, 120 miles away on the Gulf of Suez, an arm of the Red Sea, are revealing how Khufu managed to realize his ambition. The evidence indicates that he employed elite laborers who not only set the pyramid's stones but also sailed trade missions to faraway lands. The project fostered the development of a highly skilled workforce and an extensive trade network (*map on left*). This infrastructure, combined with a system of government in which the pharaoh held all the power and was considered a god, was the secret of Egypt's success in building the Great Pyramid and in generating immense wealth for centuries to come.

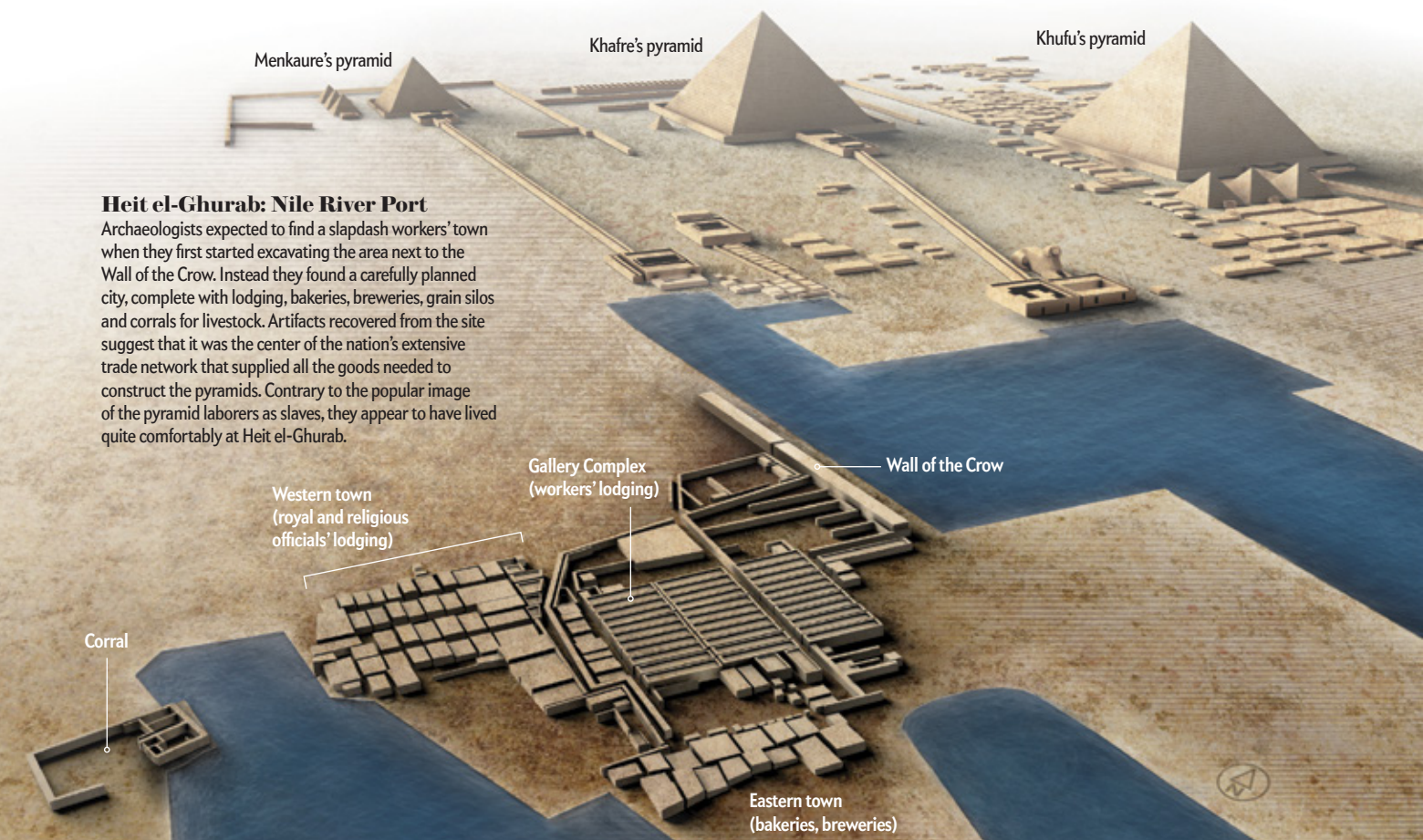




Map of the ship storage chambers at Wadi el-Jarf

Wadi el-Jarf: Red Sea Harbor

Workers needed copper tools to build the pyramids. Obtaining that copper was extremely laborious, however. Most pharaohs managed to mount only a single copper expedition. Khufu, however, amassed the resources to send at least two. He launched these expeditions from Wadi el-Jarf. Excavations are yielding an incredibly detailed picture of what happened there during Khufu's reign. One excavation area a mile from the water's edge has turned up the remains of the expedition boats, which were stored in chambers (*white bars in map above*) when not in use. Workers had to take the boats apart to store them between missions. When it was time to sail again, they had to put the vessels back together.



Heit el-Ghurab: Nile River Port

Archaeologists expected to find a slapdash workers' town when they first started excavating the area next to the Wall of the Crow. Instead they found a carefully planned city, complete with lodging, bakeries, breweries, grain silos and corrals for livestock. Artifacts recovered from the site suggest that it was the center of the nation's extensive trade network that supplied all the goods needed to construct the pyramids. Contrary to the popular image of the pyramid laborers as slaves, they appear to have lived quite comfortably at Heit el-Ghurab.

Illustration by José Miguel Mayo, Map by Terra Carta

multipocketed vest, broad-brimmed hat and a dusty pair of boots; all have absorbed the color of the desert sand. He has an air of friendly authority and is something of a local celebrity: throughout the day random onlookers shout, "Doctor Mark!" hoping to attract his attention. One of the women he is chatting with unlocks an iron gate, and Lehner leads the way into the old town.

When Lehner and his team began excavating the site, they expected to find a modest encampment at most—a handful of nondescript buildings where poor, low-status laborers would have eked out their miserable existence each night before trudging back to the pyramids in the morning to drag more stones. Instead the team uncovered something far more elaborate—a city whose layout and architecture had been carefully preplanned by Khufu's regime. Next to the wall the excavators found where the work crews lived, an area Lehner named "the Gallery Complex" because it is made up of long, narrow buildings with streets between them. The buildings each contained hearths and sleeping platforms for 20 people—the number of men in a work team—plus an extra room that may have been for their overseer.

Mud-brick walls mark the spots where the buildings stood; they are only about two feet high now, probably eroded by the desert wind. South of the Gallery Complex stood the bakeries and breweries, as evidenced by the bread ovens and beer jars found in the remains of the buildings there. South of the bakeries lies a large building next to what appear to be silos for storing grain and an enclosure wall that may have been used as a corral for livestock. West of the bakeries is a neighborhood that boasted big houses. The garbage dumps in this area showed that the residents here were eating a lot of very expensive veal, and clay sealings found in the vicinity bear the titles of high-ranking individuals, suggesting that the buildings served as the homes and offices for the city's administrators.

Far from being treated little better than slaves, Merrer's crew and the rest of Heit el-Ghurab's estimated 6,000 residents appear to have lived quite comfortably. The findings suggest that after a long day's work of unloading the barges, the pyramid builders would have headed into town to eat. The smell of baking bread and brewing beer would have wafted from the bakeries a few hundred feet away, advertising what was on the menu. Meat would have been offered, too—probably goat for the crew, beef for the foreman. And remains of distinctive ceramic shipping containers suggest that they may have had access to olive oil imported from the Levant, at the eastern edge of the Mediterranean, a frill unavailable to most Egyptians.

Why did Pharaoh Khufu invest so heavily in Heit el-Ghurab and its residents? At the time the pyramids were being built, the positioning of the Nile along the north and eastern sides of the city would have made it a prime location. Lehner believes that Heit el-Ghurab was not a ramshackle "workers' town" but a Nile port that was at the nexus of a vast trading network used to bring in all the supplies for building the pyramids. Those supplies included far more than just stone: much of the food and clothing for the workers, as well as the tools that were used in the construction. Even the luxury items owned by the priests and officials overseeing the project may have come through Heit el-Ghurab. The city was essential to pyramid operations. And the workers themselves were a precious resource. Not only did they haul the limestone from Tura, they were capable of sailing far longer trade missions, too. An analysis of the charcoal found in the workers' quarters showed that a small amount of the wood they burned was from trees—cedar, olive and pine—that grew only in the Levant, hundreds of miles away. That exotic wood may have come from broken ship parts, and it suggests to Lehner that the crews living at Heit el-Ghurab were sailing trade missions as well as setting stones.

ARTIFACTS recovered from Heit el-Ghurab include items such as bread molds (*top*) and flint knives (*bottom*). They are helping archaeologists piece together how the pyramid builders lived.

ALL FOR ONE

KHUFU EXPLOITED GOVERNMENT, labor and trade systems that his predecessors implemented before he came to power. But his pyramid project, unprecedented in its scope, drove the development of these infrastructures to dizzying new heights and in so doing primed Egypt to flourish in the centuries to come. Excavation of another site is also yielding insights into how Khufu realized his grand vision.

About 120 miles southeast of Heit el-Ghurab, Gregory Marouard looks like he is walking on the surface of the Gulf of Suez. In reality, the archaeologist treads an ancient stone pier that lies right at the water's surface here at the site of a long-ago port, now known as Wadi el-Jarf. The pier curves hundreds of feet into the sea, and Marouard is taking advantage of an extremely low tide to make precise measurements of it. Project leader Pierre Tallet of Paris-Sorbonne University stands on the beach in the battering wind, explaining the significance of the site.

Preliminary evidence suggests that Khufu's father, Sneferu, built the harbor, which offers the shortest possible crossing of the Red Sea to the Sinai peninsula's copper mines. Mining copper was a major undertaking that involved taking perhaps 1,000 workers to the mine, provisioning them for two to three months while they extracted the metal and then transporting the copper to the cities that needed it. Most pharaohs, including apparently Sneferu, launched only one copper expedition during their reigns. Khufu, however, had the money, the manpower and the will to mount at least two such expeditions, utilizing the harbor

SOURCES FOR OPPOSITE PAGE: "ON THE WATERFRONT: CANALS AND HARBORS IN THE TIME OF GIZA PYRAMID-BUILDING," BY MARK LEHNER. IN *AERAGRAM*, VOL. 15, NOS. 1-2, SPRING/FALL 2014 (*Heit el-Ghurab*); DRAWING BY D. LAISNEY
IN "AYN SUKHNA AND WADI EL-JARF: TWO NEWLY DISCOVERED PHARAONIC HARBOURS ON THE SUEZ GULF," BY PIERRE TALLET. IN *BRITISH MUSEUM STUDIES IN ANCIENT EGYPT AND SUDAN*, VOL. 18; AUGUST 2012 (*Wadi el-Jarf map*)

far more intensively than his father ever had. He needed to do so to obtain enough copper to make the many chisels, saws and other tools required to build the Great Pyramid. Wadi el-Jarf is a rare find. "We know nothing about harbors in the ancient Egyptian period," Tallet reflects. "This is probably the oldest harbor ever found."

Evidence linking the harbor to Khufu's expeditions is everywhere at Wadi el-Jarf. For example, a few hundred feet from the water's edge, excavators are working on two long, rectangular buildings that are separated into cells of equal size. One building is made up of five cells, and the other is made up of 10. Tallet says that the cells may have housed both the cargoes and the crews of ships. Dozens of clay sealings have been found throughout these buildings. Goods were often shipped in bags that were tied with rope and sealed with a blob of clay that was impressed with the seal of whoever owned the bag's contents. Many of the sealings bear Khufu's name.

Other finds document the activities that took place at Wadi el-Jarf in startling detail. Tallet's team has focused much of its energy on excavating a series of chambers that were dug into a hillside about a mile from the beach. In between copper expeditions the boats were disassembled and stored in these chambers. Many of them still contain pieces of rope from the rigging and even some small pieces of wood with red-ink inscriptions indicating how to reassemble the boats.

Even more remarkable, the excavators discovered the papyrus records that Merrer had written some 4,500 years ago during one of the final years of Khufu's rule. It has taken Tallet years to conserve and reassemble the bits of papyrus, but the fragments clearly contain the best records available of the day-to-day activities of ancient Egyptian laborers. After delivering the Tura limestone to Giza, Merrer took his crew north to build a port on the Mediterranean Sea. When that mission was completed, they were sent to Wadi el-Jarf, from which he would transport copper at the end of Khufu's reign in 2525 B.C. Merrer's first order of business at Wadi el-Jarf would have been to have his men open the chambers where the dismantled boats were stored, carry them to the beach and begin putting the 80-foot-long vessels back together, following the instructions inscribed on each piece in red ink. They then spent a few months ferrying food from Egypt to Sinai for the miners and bringing back the newly mined copper to Wadi el-Jarf.

Nearly everything Merrer's crew did, according to the papyrus, was in service to the construction of the Great Pyramid. What, if not slavery, motivated these men to apply their many skills to this project and not some other venture? Clues come from the history of Egyptian government. From its beginning in 2950 B.C., Egypt was different from other states that existed at the time. The first pharaoh, Narmer, had brought all of Egypt from the Mediterranean coast south to the granite quarries at Aswan under his control through sheer military might. At the same time, Mesopotamia was ruled by dozens of small city-states, each governed by its own king, who shared power with other religious figures and wealthy families, says Pascal Butterlin of Pantheon-Sorbonne University in France. Egypt was probably the largest area controlled by one ruler in the world at the time, and the ultimate authority for all things within its borders was the pharaoh.

The concentration of all religious and political power in the hands of the pharaoh meant that Egyptian society operated in a different way from other kingdoms, such as the Mesopotamian city-states, that existed at the time. Whereas Mesopotamian kings claimed a close relationship with their gods, the Egyptian pharaohs believed they actually were gods. Bob Brier, an Egyptologist at Long Island University, thinks the divine kingship of the pharaohs allowed them to command the obedience of their subjects in a way that the rulers of other states could not. Egyptian texts support this idea, according to Henry Wright, an expert in the formation of early states at the University of Michigan. They show that the laborers were religiously motivated and were probably coming to work on the pyramids out of an ideological commitment, not just a need to perform a certain amount of labor that they owed to the nation under Egyptian law. "They are not just building a tomb for some guy," Wright observes. "They are building a tomb for a god." That distinction may have been what made the pyramids possible.

A TIPPING POINT

IN TURN, THE PYRAMIDS and the infrastructure they necessitated made other things possible. Although Wadi el-Jarf was abandoned just 50 years after it was built, having served its purpose, it paved the way for the building of another, far more successful port farther north. Called Ayn Sukhna, this port was closer to the capital city of Memphis and other places where copper was needed, including Giza and later the funerary complex at Abusir, located about eight miles south of the Great Pyramid. Ayn Sukhna would play a lasting role in building Egypt's wealth, sending and receiving cargo ships from across the Red Sea for nearly 1,000 years.

For its part, Heit el-Ghurab continued to be a major focal point of trade through the rest of the fourth dynasty, when Khufu's successors Khafre and Menkaure built their own pyramids. But after Menkaure was laid to rest, the age of the Giza pyramids was over. In 2450 B.C., when the fifth dynasty began, funerary monuments became much more modest, and the city at Heit el-Ghurab was abandoned. At first glance, these changes might seem to signal a downturn for Egypt. Large building projects

SCIENTIFIC AMERICAN ONLINE For more photographs of Heit el-Ghurab and Wadi el-Jarf, go to ScientificAmerican.com/nov2015/pyramid

AT THE SITE of Wadi el-Jarf on the Red Sea, archaeologists have found remnants of the oldest known harbor (*left*). Artifacts include such fragile remains as the fragment of inscribed papyrus above.

such as the pyramids are often considered general indicators of a society's wealth. Indeed, for decades many Egyptologists have thought that the pharaohs stopped building gigantic monuments to themselves because the nation had grown poorer.

Lehner makes a different argument. He thinks priorities shifted at the beginning of the fifth dynasty and the trade and labor infrastructure that earlier pharaohs had created to build the pyramids were redirected to build projects in the provinces that helped to sustain the nation's prosperity for centuries. This infrastructure was a hugely powerful tool, one with coordinated supply chains of resources that spanned hundreds of miles beyond Egypt's borders and organized the efforts of more than one million people under a single authority. "The network became more important than the reason that created the network in the first place," Lehner asserts. "It was a tipping point toward modernity."

Modernity, in Lehner's view, is the development of a more complex bureaucracy with distributed organization that fosters local control over labor and resources, rather than direct control by the pharaoh's family. Evidence for this complex bureaucracy comes from the Palermo Stone, a piece of a carving discovered sometime before 1877 that recorded the achievements of pharaohs from the third through fifth dynasties. Entries made during the reign of Userkaf, the first pharaoh of the fifth dynasty, show that he increased the number of plantations being created and made tremendous donations of land to the cult of the Sun God Ra as ways to spur development in the countryside. Overseeing this expansion required more bureaucrats, who then wanted to show off their status with luxury goods and big tombs. Supplying these new rural populations, meanwhile, increased demand for basic goods. The result was a self-sustaining feedback loop of demand and supply that not only created wealth for Egypt but also lifted the economies of its trading partners abroad.

Wright agrees with Lehner up to a point. "It's certainly a tipping point," he allows. "It is an organizational revolution." But he balks at calling it modernity. In Wright's view, Egypt in the fifth dynasty was missing one of the defining characteristics of a "modern" society: a change in thought systems. Modern societies, he argues, have rapidly growing bodies of technical knowledge and systems confirming and verifying that the information is true. Although the ancient Egyptians certainly had an important body of technical knowledge, much of their knowledge was ritualized and obtained through divination.

Disagreements over what constitutes modernity notwithstanding, scholars agree that Egypt's sophisticated system of control was a significant advance. Future excavations should reveal exactly how this development played out. Tallet plans to continue scouring Wadi el-Jarf for more evidence of the extent of Egypt's trade network. He also continues to translate Merer's records of the work that his crew completed. Tallet suspects that trade missions to the land of Punt, which is believed to be in modern-day Sudan, sailed out of Wadi el-Jarf, but he has yet to establish that connection. Meanwhile Lehner will continue the enormous job of excavating Heit el-Ghurab and analyzing the emerging clues about life in the city long ago.

Yet the best evidence of the economic revolution that the pyramids wrought may not be in Heit el-Ghurab or Wadi el-Jarf or on the Giza Plateau. Lehner points to outposts in Egypt's Western Desert and estates at Shaykh Sayed in middle Egypt as places that may yield further indications that it was the small communities far from ancient Egypt's urban core that benefited from the wealth that poured into the nation as a result of its centralized bureaucracy under a divine king. In the end, Khufu's true achievement was not erecting the Great Pyramid but rather building a network of trading partners and organizing the labor of an entire nation. "It wasn't a technological wonder," Brier says of Khufu's monument. "It was a sociological wonder." SA

MORE TO EXPLORE

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FROM OUR ARCHIVES

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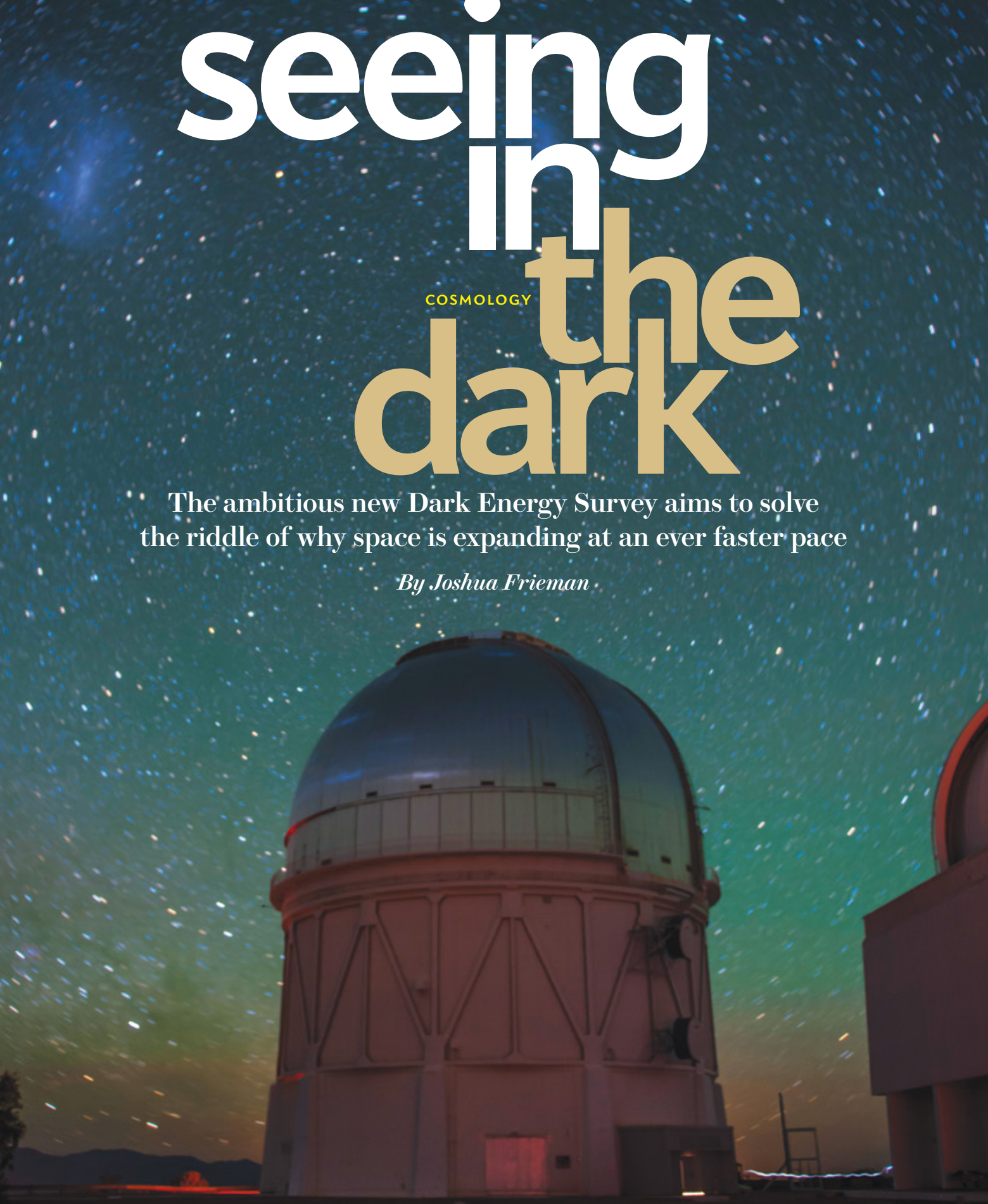
scientificamerican.com/magazine/sa

seeing in the dark

COSMOLOGY

The ambitious new Dark Energy Survey aims to solve the riddle of why space is expanding at an ever faster pace

By Joshua Frieman



DARK ENERGY CAMERA, installed recently on the Victor M. Blanco Telescope in Chile, enables astronomers to survey the accelerating cosmos.

Joshua Frieman is a theoretical and observational cosmologist and director of the Dark Energy Survey. He is a senior staff scientist at Fermi National Accelerator Laboratory in Batavia, Ill., and a professor of astronomy and astrophysics at the Kavli Institute for Cosmological Physics at the University of Chicago.

NEARLY 100 YEARS AGO EDWIN HUBBLE DISCOVERED that the universe is expanding: almost all galaxies are speeding away from our own Milky Way, and faraway galaxies are receding faster. That discovery was profound, but it was followed, in 1998, by an even more startling realization: the expansion is accelerating. For most of the 20th century, scientists had expected that over time gravity would pull galaxies toward one another, slowing the expansion. Instead two teams of astronomers studying supernovae—exploding stars that serve as markers for measuring cosmic distances—found that the growth of the universe is actually speeding up. This remarkable discovery, since confirmed by other observations, was awarded the Nobel Prize in Physics in 2011. But *why* is the universe accelerating? This enigma is one of the biggest unsolved mysteries in all of science.

To explain it, cosmologists have come up with two alternative ideas, either of which would revolutionize our understanding of the laws of nature. One is that Isaac Newton (and more recently, Albert Einstein) did not have the last word on gravity: although gravity is attractive on Earth and in the solar system, perhaps it acts differently, becoming a repulsive force, when it comes to the vast distances of intergalactic space. Maybe we need to modify the theory of how gravity operates on cosmic scales.

The other idea is that the universe is filled with some unseen stuff—now called dark energy—that counteracts the force of gravity, making objects repel instead of attract one another. Cosmological measurements indicate that dark energy, if it exists, currently makes up about 70 percent of the universe by mass or energy (mass and energy are equivalent, as Einstein showed with his equation $E = mc^2$). Dark matter (no relation to dark energy), an invisible form of matter, makes up about 25 percent, and normal matter—things made of atoms, including stars, planets and people—contributes only about 5 percent. This picture has garnered more attention than the notion that gravity works differently on large scales because it neatly explains the formation of galaxies and larger structures in the universe and is consistent with all measurements to date.

But how can we know for sure if dark energy is to blame for cosmic acceleration? And if it *is* dark energy, what is the nature of this stuff? We recently launched an ambitious project called the Dark Energy Survey (DES) to better understand why the universe seems to be ripping apart.

The survey should provide answers by gathering a thorough record of the 14-billion-year history of cosmic expansion and the rate of growth of large-scale structure—the vast conglomerations of galaxies spread across the universe—with unprecedented precision. By studying how structures grouped together over time, we hope to distinguish among the various possibilities for why they are pulling apart now.

My colleagues and I at Fermi National Accelerator Laboratory and the University of Chicago, along with 300 other physicists and astronomers from 25 institutions in the U.S., Spain, the U.K., Brazil, Germany and Switzerland, make up the DES collaboration and have worked together to build, operate and analyze data from the Dark Energy Camera, the hardware heart of our project.

In 2012 we mounted this camera on a four-meter-diameter telescope at Cerro Tololo Inter-American Observatory, a U.S. facility high in the Andes Mountains of northern Chile. It took its first snapshots of the night sky that September and was commissioned over the following months. On August 31, 2013, the

IN BRIEF

Something is causing the expansion of the universe to speed up—but what? Scientists have proposed that a force called dark energy is behind the acceleration or, alternatively, that current understanding of gravity must be modified. If dark energy is the culprit, at least two explanations are possible.

A new project called the Dark Energy Survey (DES) will aim to solve this mystery by studying the history of cosmic expansion and the extent to which dark energy may have stymied the clumping together of galaxies throughout space.

It will tackle these questions in four ways—through observing supernovae, the signatures of primordial sound waves, gravitational lensing (the bending of light by matter in the universe) and clusters of galaxies.

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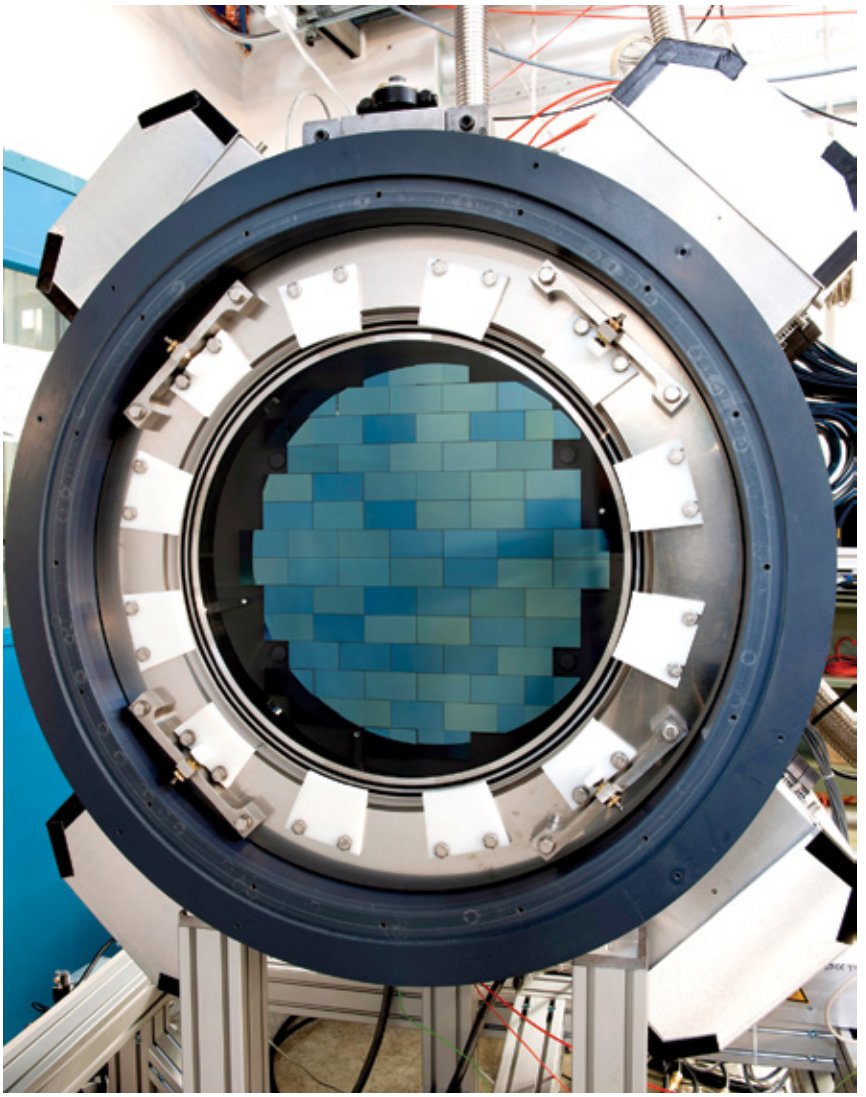


IMAGER for the Dark Energy Camera (*shown above*) consists of 74 silicon CCD (charge-coupled-device) light sensors, which cover a very wide field of view to survey the cosmos.

DES officially began surveying a large swath of the southern sky. The survey, now in its third season, will run from August to February every year for five years and ultimately produce a deep, high-resolution map of about 200 million galaxies spread over one eighth of the sky as well as a catalog of stellar explosions that can be used to track cosmic expansion. The survey has already collected a wealth of new data that is currently being analyzed and on the way toward unlocking the secret to the universe's expansion.

COMPETING HYPOTHESES

FORTUNATELY FOR SCIENTISTS, the same evidence that should distinguish between the modified gravity and dark energy hypotheses of acceleration should help clarify what dark energy is, if it exists. The survey will test two main ideas about dark energy. The simplest explanation for it may seem counterintuitive: that it is the energy of empty space. Suppose you took a box and emptied it of all matter—all the atoms, radiation, dark matter, and so on—and nothing could penetrate its walls. The inside of the box would be a perfect vacuum. According to classical physics, the vacuum—empty space—has no energy. But quantum theory says that even empty space carries energy. Physicists think of this energy as coming from "virtual" particles: at any time a particle and its antiparticle can appear spontaneously for a brief instant, then annihilate each other and disappear back into the vacuum. Virtual particles carry energy in exactly the form that would be needed to constitute dark energy and cause the expansion of the universe to speed up.

The only difficulty with this notion is that quantum physics predicts that the amount of vacuum energy in space should be 120 orders of magnitude (10^{120}) larger than what it seems to be if it is responsible for dark energy. If you are working on a math problem, it is hard to make an error that big. Partly as a result of this discrepancy, cosmologists have proposed other explanations for dark energy aside from vacuum energy.

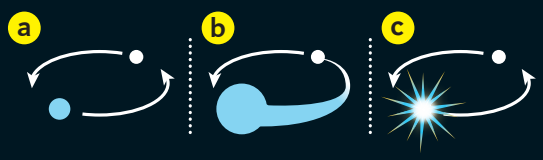
One idea—the second notion being tested by the survey—is that dark energy takes the form of a so far undetected particle that could be a distant cousin of the recently discovered Higgs boson: it would have some of the properties of the Higgs particle but would be 44 orders of magnitude lighter. This possibility is sometimes dubbed "quintessence." One can think of such a particle as acting like a ball rolling down a hill at each point in space. The rolling ball carries both kinetic energy (because of its motion) and potential energy (because of the height of the hill it is rolling down); the higher an object is, the greater its potential energy is. As it rolls down, its potential energy declines, and its kinetic energy rises. If the quintessence particle is extremely light, with a mass less than about 10^{-33} electron volt (the electron, for example, has a comparatively huge mass of 511,000 electron volts), then it would be rolling very slowly today, with relatively little kinetic versus potential energy. In that case, its effect on cosmic expansion would be similar but not identical to that of vacuum energy and would lead to acceleration, although most versions of the quintessence idea predict that the acceleration would begin later in cosmic history than if vacuum energy were the culprit.

FOUR PROBES

TO DISTINGUISH AMONG the possible causes of cosmic acceleration, the Dark Energy Survey—which is funded by the U.S. Department of Energy and the National Science Foundation, with additional support from the participating institutions and foreign

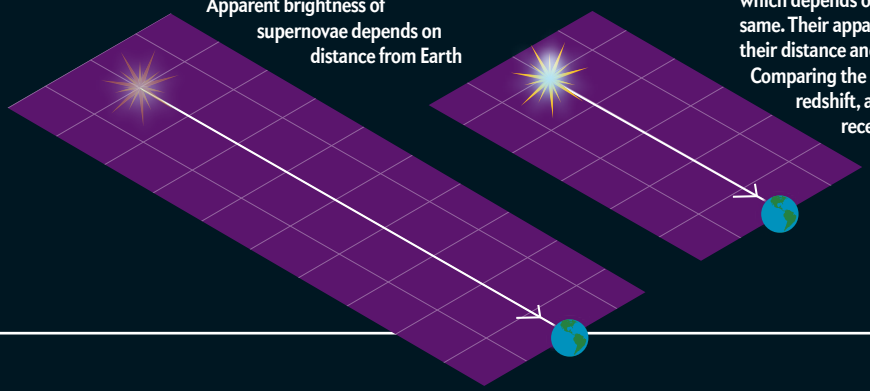
Cosmic Acceleration: Four Approaches

The universe is expanding at an ever faster rate, and the Dark Energy Survey (DES) aims to find out why by observing four different signals. The left two measure cosmic distances to see how large the universe was and how fast it was expanding at various epochs. The right two map the clumpiness of matter throughout space to gauge the competition between gravity and the force behind the universe's acceleration. Certain patterns of expansion and clumping over time would suggest that the universe's acceleration stems from one or another form of dark energy—a hypothesized constituent of space that counteracts the force of gravity. Other patterns, meanwhile, could indicate that, to explain the acceleration, scientists must rewrite the laws of gravity for cosmic scales.



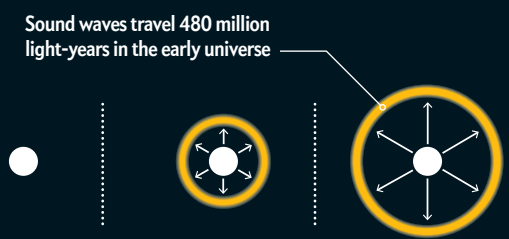
Brightness of Type Ia Supernovae

These stellar explosions result from particular types of dense stars called white dwarfs. In one possible scenario the white dwarf pulls matter off a companion star (a) to become more and more massive (b), until it reaches the white dwarf mass limit, triggering a supernova (c). Because all type Ia supernovae produce nearly the same amount of radioactive material, their intrinsic brightness, which depends on that material, is nearly always the same. Their apparent brightness, then, depends only on their distance and thus reveals how far away they are. Comparing the distances of supernovae with their redshift, a measurement of how fast they are receding from us, reveals how fast the universe was expanding at different cosmic epochs.



Signatures of Sound Waves

Sound waves emitted in the early universe traveled through space at nearly the speed of light until the cosmos had cooled enough for atoms to form. The distance covered by the waves up to that point—which corresponds to 480 million light-years today—made it slightly more likely that two galaxies would form with just that much space between them. This effect shows up as a slight excess of galaxies in a spherical shell with a radius of 480 million light-years from a given galaxy. On the sky, we see an overdensity of galaxies in an angular ring around the central galaxy. Because astronomers know the absolute radius of the ring, they can measure the angle on the sky the ring covers to infer the distance to the galaxies—the farther away they are, the smaller the angle. These distances, in turn compared with the galaxies' redshifts, map out the expansion history of the universe.



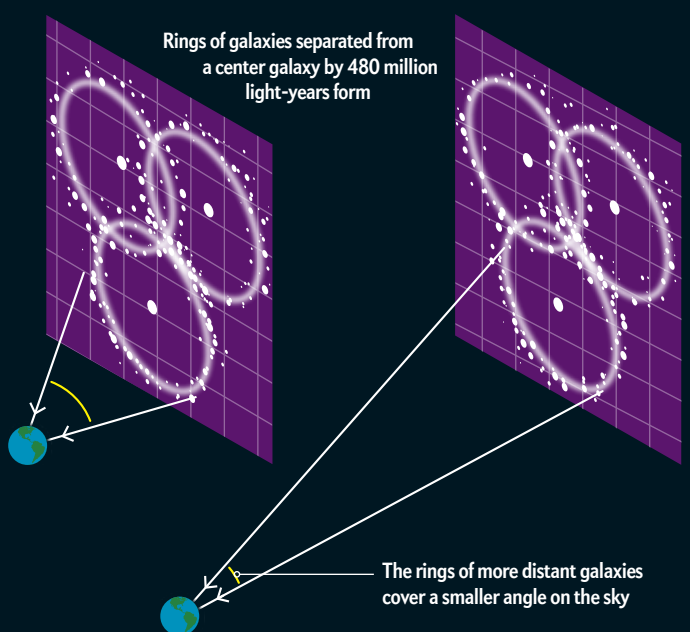


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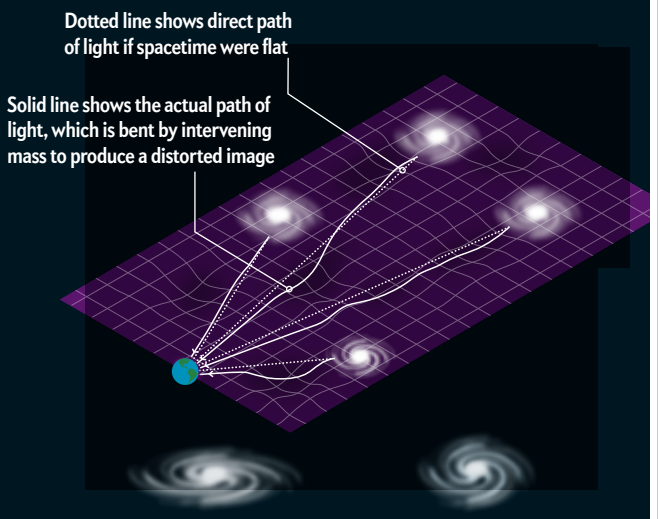
Illustration by Nigel Hawtin

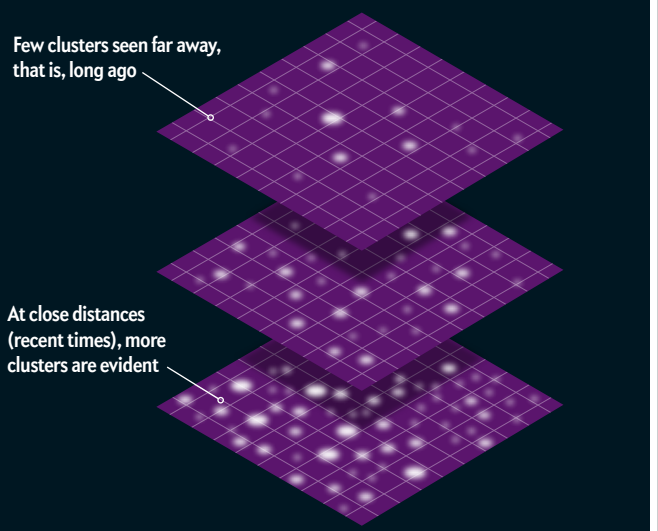
Extent of Gravitational Lensing

The light from distant galaxies will bend when it passes massive objects—such as galaxy clusters—on its way to Earth. This bending—an effect called gravitational lensing—causes the galaxies' shapes to appear distorted in the telescope. The experiment will measure the slight distortions of many galaxies to create a map of how mass is spread through space. The degree to which galaxies at different distances from us are gravitationally lensed will reveal the clumpiness of matter at different epochs of the universe.



Clusters of Galaxies

Over time gravity pulls galaxies together into clusters, against the push of whatever is causing cosmic expansion to accelerate. The DES will hunt for tens of thousands of clusters out to billions of light-years away and compare the numbers of clusters seen nearby, corresponding to recent times, and far away, corresponding to long ago, to learn how fast galaxies have clumped together over time.



funding agencies—is investigating four phenomena that are particularly sensitive to whatever is pulling the universe apart. And because each involves a different observable quantity, the four probes will not all be affected by the same measurement errors.

These four phenomena are supernovae, signatures of primordial sound waves, gravitational lensing (the bending of light by gravity) and galaxy clusters. Collectively they tell us how fast the universe has expanded and how much matter has clumped together to form large-scale structures at different epochs of cosmic history. At early times, up to about several billion years after the big bang, gravity fought against the expansion and enabled large-scale structures to form. But when the universe was around seven billion years old, matter became dilute enough that whatever was causing accelerated expansion—be it dark energy or modified gravity—became dominant over gravity and sped up the expansion, gradually shutting down the further formation of large structures. Vacuum energy, quintessence and modified gravity would each leave unique signatures in the history of the cosmic expansion rate and in the pattern of structure growth, imprints that we can tease out through these four probes.

SUPERNOVAE

A TYPE IA SUPERNOVA is a unique category of stellar explosion that results when a small, dense object called a white dwarf star reaches a certain mass limit. These supernovae have a very special quality—they all reach a peak brightness that is nearly the same. Any differences in how bright they appear to us stem solely from their distance: those that look dimmer are farther away. This feature makes them so-called standard candles, or good cosmic yardsticks. We know, for instance, that a type Ia supernova 100 times as faint as another is 10 times farther away.

The DES will observe the same few patches of sky every few nights to measure accurate distances to a few thousand type Ia supernovae in the nearby and distant universe, nearly 100 times as many as were used in the 1998 discovery of cosmic acceleration. We are also using other telescopes to measure how much the light from these supernovae is shifted toward the red end of the visible spectrum. This redshift occurs for any object speeding away from an observer and tells us how much the wavelength of the light has been stretched by the expansion of the cosmos between the time it was emitted and now. The redshifts of the distant supernovae directly reveal the relative size of the universe then versus today. Taken together with the standard candle distance measurements to the same objects, the DES will be able to reconstruct the past 10 billion years of the expansion history of the universe with great precision.

Such a measurement can distinguish among different theories of cosmic acceleration because each would have produced a slightly different expansion history. If quintessence is at work, for example, accelerated expansion would have started somewhat later than in the vacuum energy scenario and built up more gradually, most models suggest. Thus, supernovae of a given redshift will appear brighter—will be closer—if the universe contains a Higgs-like quintessence particle than they will if vacuum energy is driving expansion. And if gravity, in turn, works differently than we think, the pattern among distant supernovae will again differ, although the details vary depending on the specific modifications investigators have proposed to the classic idea of how gravity works.

Very high precision in these measurements is necessary to distinguish among the different models because their predictions diverge only slightly. Therefore, we wish to know the distance versus redshift relation to roughly single-percent-level accuracy—a feat that the Dark Energy Camera, for the first time, should be able to manage.

SIGNATURES OF PRIMORDIAL SOUND WAVES

THE DES WILL ALSO USE a relic from the beginning of the universe to study its expansion history. In the early universe, gravity was pulling matter together while the outward pressure of the electromagnetic radiation (light) in the cosmos resisted such compression. This competition created a series of sound waves. A few hundred thousand years after the big bang, when ordinary matter had cooled sufficiently from its initial hot state to transition from an ionized gas into atoms, the atoms and radiation went their separate ways (they effectively stopped interacting with one another), and this competition ceased. The distance traveled by the sound waves up to that point, which today corresponds to a scale of about 480 million light-years, ended up imprinted in the spatial distribution of galaxies as a slight tendency for pairs of galaxies to be separated by this distance compared with other distances.

This baryon acoustic oscillation (BAO) scale provides a standard ruler for measuring cosmic distances and the expansion history. That is, if you know the physical size of a ruler (the 480-million-light-year spread of many galaxies from one another) and can measure how big it appears (the angle of separation between those galaxies on the sky), then you can tell how far away it is. The DES will measure this BAO feature for about 200 million galaxies, enabling us to chart their distance versus their redshift as we do for supernovae. Galaxies of the same redshift would be closer if quintessence caused the universe to start accelerating later than if vacuum energy was responsible and acceleration began earlier. If there is no dark energy, we expect that the relation between distance and redshift will look different from either of those scenarios, although the particulars will again depend on how exactly gravity is altered.

GRAVITATIONAL LENSING

THIS METHOD FOCUSES on a feature of light predicted by Einstein's general theory of relativity. The paths of light rays, as they travel to Earth from distant galaxies, get bent by the gravitational field of the matter they pass. This bending leads to a distortion of the images of these galaxies, an effect known as gravitational lensing. When the bending effect is large, the resulting images can be dramatic: distant galaxies may appear as thin, very extended arcs of light, and one may even see multiple images of the same galaxy. The light rays from most galaxies, however, are bent only slightly, leading to very small distortions in their shapes that are not discernible by eye: this is the regime of *weak* gravitational lensing.

Light rays from equally distant galaxies near to one another on the sky get bent by nearly the same amount because they travel through roughly the same intervening matter. By measuring the shapes of many galaxies in a small patch of sky, we can infer how much the images have been distorted and thus the clumpiness of the intervening matter, even though each galaxy image is distorted only slightly. Repeating this measurement for galaxies in different parts of the sky thus reveals the general clumpiness of matter in the universe. The evolution of this clumpiness over time, because it reflects the competition between gravity and dark energy and is sensitive to any modification of gravity, can help tell us what is causing the universe to accelerate.

The DES will measure the shapes of 200 million galaxies to see this effect, covering over 20 times more galaxies and a greater area of sky than previous weak lensing studies. By making extremely precise measurements of the shapes of these galaxies across the sky at different distances from Earth, we can create the most precise map yet of the distribution of matter at various removes—that is, at various cosmic time periods because the farther something is from Earth, the longer its light takes to reach us.

The map will differ depending on what is pulling the universe apart. The effects of quintessence in hindering the growth of large-scale structure, for example, probably set in during an earlier cosmic epoch than those of vacuum energy. Because we know from measurements how clumpy the universe is today, if quintessence were at work, we would expect to see more clumpiness when the universe was younger than in the case of vacuum energy. That prediction may sound counterintuitive because dark energy would hinder clumps from forming, but for the universe to have its current structure after billions of years of expansion, it would have to have been relatively clumpy early on. If there were no dark energy, modified gravity would have led to yet a different pattern of clumpiness throughout time—although whether the clumpiness would be relatively more or less at early epochs would differ for different formulations of the laws of gravity.

GALAXY CLUSTERS

FINALLY, THE DES will also hunt for clusters of galaxies to trace cosmic clumpiness over time. Clusters, with masses of up to more than 10^{15} (1,000 trillion) times the mass of the sun, are the largest gravitationally bound objects in the universe, and they form against the pull of either dark energy or modified gravity. Unlike previous cosmological cluster surveys, which have been limited to smaller areas of sky, the DES aims to discover tens of thousands of clusters out to billions of light-years away.

Scientists will then compare the number of clusters they see close to Earth—corresponding to recent times—and far away in the past. Similarly to the effects on matter's clumpiness as shown by weak gravitational lensing, we expect to see more clusters in the early universe if quintessence is at work than if vacuum energy is shaping the cosmos (all other things being equal), and we would see a different and more complicated trend altogether if gravity behaves unusually.

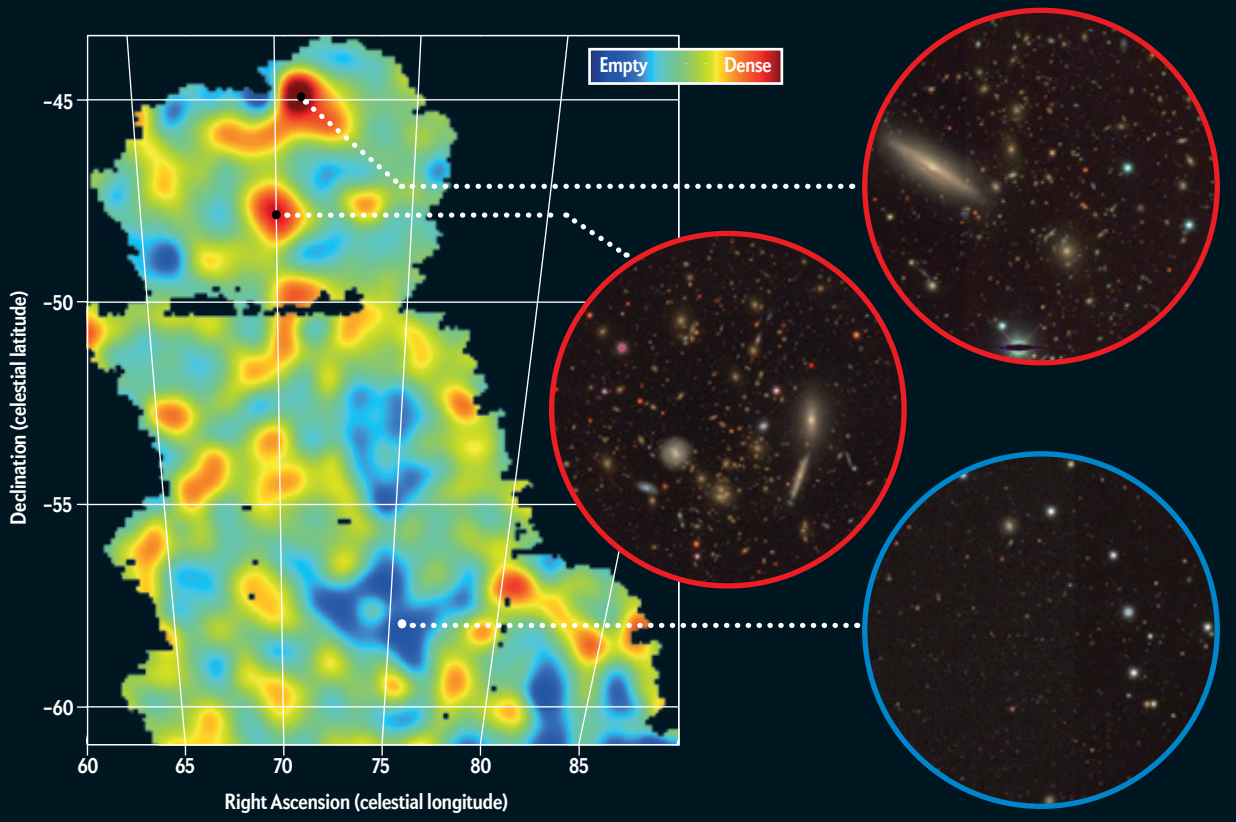
STATE-OF-THE-ART INSTRUMENT

THE SECRET WEAPON for our project is the most powerful camera ever made for looking into this question. The Dark Energy Camera, mounted on the Victor M. Blanco Telescope, is designed to survey numerous objects, including galaxies, clusters and supernovae, in the shortest possible time. The ultrasensitive, 570-megapixel camera has a very large field of view, enabled by five large lenses, best for taking in large swaths of the universe at a go.

Since its official start in August 2013, the survey has covered nearly 5,000 square degrees of sky, obtaining color images of about 100 million galaxies. The supernova survey has discovered more than 1,000 type Ia supernovae so far. We are now analyzing these data to extract information about the supernovae's distances to compare with redshift. We are also measuring galaxy shapes

Mapping Mass

This map shows the large-scale distribution of mass over roughly 139 square degrees of the sky—an expanse about 650 times the size of the full moon. Red regions are areas with a higher than average density, whereas blue represents emptier spots. The Dark Energy Survey created this map by measuring weak gravitational lensing—the slight bending of light from distant galaxies caused by the gravity of all the mass (including both visible and dark matter) in the intervening space that the light traveled through. The inset photographs, taken by the Dark Energy Camera, show close-ups of three regions in the mass map. The two red circles, corresponding to overdense areas, display a number of bright galaxies; the blue circle shows relatively few galaxies, consistent with the region's comparatively low density.



COURTESY OF JOE ZUNTZ, MICHAEL TROXEL AND DES COLLABORATION (*map and galaxy photographs*)

to infer the weak lensing signal, identifying distant clusters of galaxies and measuring their properties, and measuring the spatial distribution of galaxies to hunt for the baryon acoustic oscillation signature. In about a year, the first phase of this analysis should be complete, and we can begin to look for clues that reveal the nature of the universe's expansion.

In the meantime, the experiment has made some interesting astrophysical findings, such as the discovery of 16 ultrafaint dwarf galaxy candidates in the Milky Way's backyard. These very nearby galaxies contain as little as a few tens of stars and are among the most dark matter–dominated objects known in the universe. Their darkness makes them very hard to detect, but they are of interest as the building blocks of larger galaxies like our own Milky Way and as potential sites for probing the nature of dark matter.

More DES data are coming in all the time. As you read this, scientists are analyzing these observations for clues to the nature of dark energy. We do not yet know whether the DES will provide definitive answers—dark energy or modified gravity? vacuum energy or quintessence?—but we do know it will take the next major step in the hunt for dark energy and for the root cause of our universe's mysteriously accelerating expansion. SA

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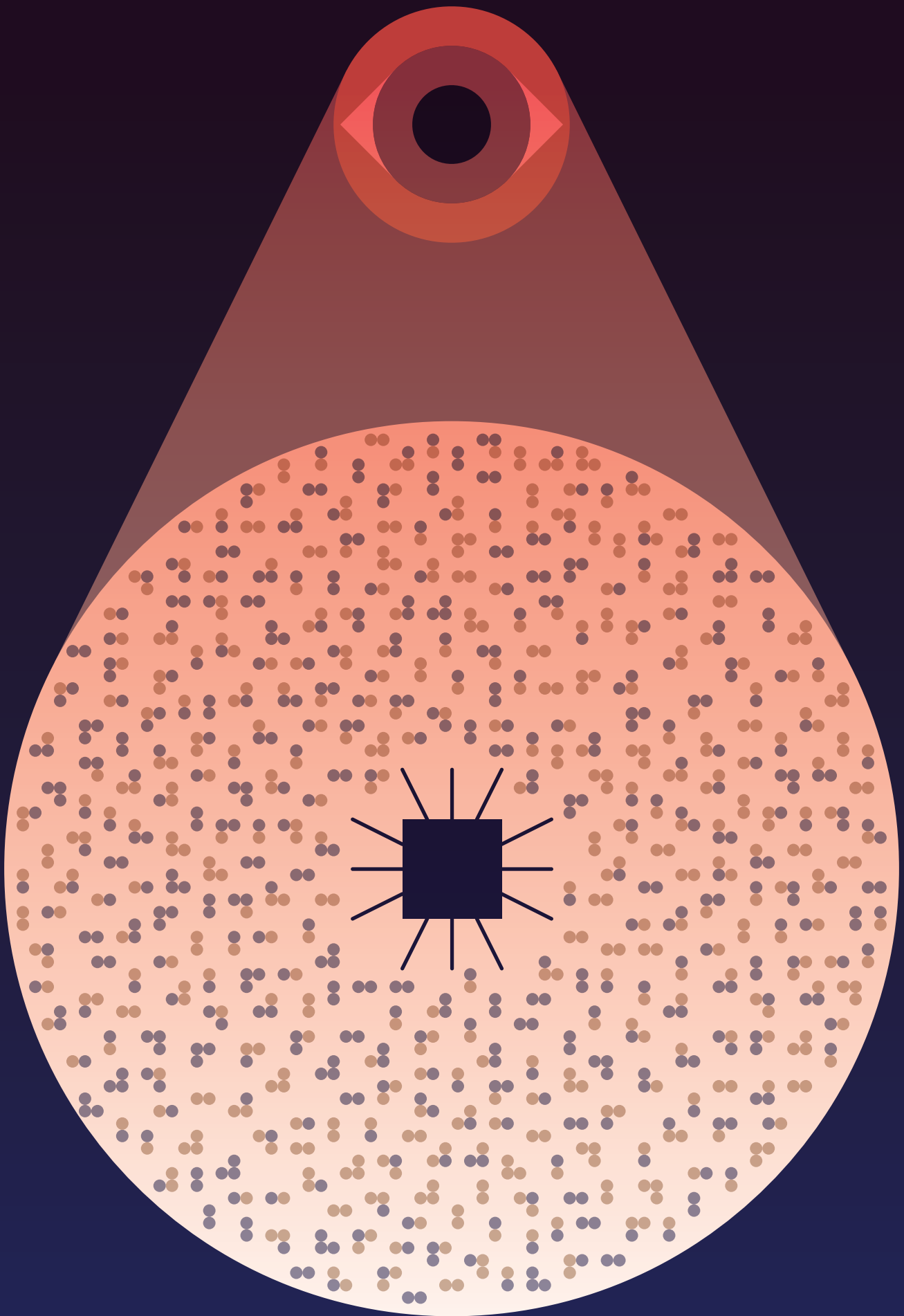


MEDICINE

DISEASE DETECTOR

Tiny new probes can diagnose infections in 20 minutes, knocking days off the wait for results and saving lives

By Shana O. Kelley

Why is it so difficult to diagnose an infectious disease on the spot?

We measure vital signs such as temperature or blood pressure routinely, yet we have no quick way to pinpoint the cause of most infection. Our inability to identify harmful bacteria and viruses costs patients dearly. During the several days or so that doctors usually take to identify bacteria and viruses, illnesses spread and may get harder to treat, and the most vulnerable patients—newborns, the elderly, anyone with a weak immune system—can die.

These delays happen amid all the advantages of high-tech medicine. Consequences are even worse in small clinics in Africa, where it can take many more days to get test results. In that time, malaria patients can be mistakenly treated for typhoid, or Ebola patients can go unquarantined.

Tests move so slowly because the molecular fingerprints of specific infections are hidden in the human body, obscured by an abundance of normal proteins and particles. In one sample of blood, there can be just 1,000 bacteria-specific molecular markers floating among trillions of irrelevant molecules. It takes a long time for expensive, complex machines, operated by highly trained scientists in specialized laboratories, to find a large enough group of target molecules to set off an alarm.

We are now on the verge of doing much better. Instead of wasting time and endangering lives transporting samples from patients to testing facilities, we can find the molecules of disease right away, identifying them in a doctor's office while the patient waits 20 minutes. We can do this with nanoscale probes, tiny sensors just a few billionths of a meter in diameter that are nestled in a small, plastic cartridge. Place a drop of blood in the cartridge and get the results. These probes react quickly to low levels of bacterial DNA, in part because they are about the same size.

Size matters. A small wave will not shake a battleship, but it

IN BRIEF

Typical tests to diagnose infections are slow because it takes time to find enough DNA from an invader.
During the days-long lag, patients can get the wrong drugs, or get sicker, or slip away from health care.
New devices, using nanoscale chemistry, could provide accurate results in minutes, right in a doctor's office.

Illustration by Greg Mably

will rock a little rowboat in a clearly noticeable way. It might send spray over the sides, startling the rower. Our nanoscale probes respond to their surroundings—fluid in a blood sample—in ways that would go unnoticed by a larger sensor, and we can see that happen very quickly.

My colleagues and I are excited to see that our systems will be tested in the clinic in the coming year. And ours is only one of several promising diagnostic approaches, developed by other researchers, that also use nanoscale reactions. Scientists have refined methods of shaping materials, often atom by atom, during the past decade. Laboratories across the world are using this fine-grained control to design devices that react more quickly, to highly specific triggers, than larger predecessors. We are all cautious because we have seen real-world instances where our prototype successes have fallen short. But we are hopeful, too, that such methods will eventually help us deliver care the moment it is needed.

Shana O. Kelley is a Distinguished Professor of chemistry, biochemistry, pharmaceutical sciences and biomedical engineering at the University of Toronto. She is a director of, and holds equity in, Xagenic, a company that commercializes technology described in this article.

FISHING FOR DISEASE

MY RESEARCH GROUP got into this area about 10 years ago. We were looking with admiration at the simple, user-friendly handheld glucose monitors used by people with diabetes. The glucose molecules essentially complete an electrical circuit in the device by giving up some of their electrons, creating a current. More current means more blood glucose. We wondered if we could use the same approach to measure DNA and RNA sequences from bacteria or viruses that are specific markers of infection.

To make this work, we needed to find a way to attract and catch some DNA molecules from these pathogens that might be present in a sample of blood taken from a patient. We were going fishing, so we needed bait. One nice feature of any piece of DNA is that it will stick, very selectively and tightly, to another sequence of DNA that we can design and synthesize ourselves. We could create a sequence to catch, say, DNA from a staph bacterial strain. That gave us our highly specific lure. We attached that lure molecule to a sensor, a millimeter-wide gold wire, designed to give off an electric current when the bacterial DNA hit. (Gold works well because it is a good current conductor.)

But because DNA, on its own, does not release enough electrons to start sucking a detectable electric current out of the gold wire, we added an amplifier. We mixed in a metal molecule, ruthenium, to our sample. This metal has a positive electrical charge, so it is attracted to the DNA, which has a negative charge. If a DNA molecule bound itself to our sensor, the metal would come along for the ride. The metal-DNA complex readily grabs electrons from the gold wire, which starts the flow of current at a level that we can detect. By using different bait molecules on the surface of our sensors, we could spot DNA from different kinds of bacteria.

The bad news was that in situations close to real life, this method did not work. It performed well enough when we dumped a great deal of bacterial DNA—trillions of molecules—into our samples. But then we tried it with levels of DNA that were closer to what typically show up in a blood sample that a doctor might draw with a needle. Usually such a sample contains 1,000 target molecules or fewer. We tilted the scales in our favor, using a million targets, but even then we could not get a detectable signal. We were nowhere near where we needed to be.

We spent a year exploring all the variables in our system and trying to understand why we could not find smaller numbers of molecules. It was frustrating—none of the tweaks we could think of seemed to make the method more sensitive. A couple of the students in the group actually gave up and asked to be transferred to different projects. I was beginning to have doubts myself and wondered if my research group was going to survive.

Thankfully, serendipity intervened. One day, in 2004, we were discussing work on an unrelated project that also involved the use of gold but on a much smaller scale. These gold nanowires were just 10 nanometers (10 billionths of a meter) across, an amount of space that could hold only five DNA molecules. So just for fun—and because nothing else was working—we swapped these nanowires for the millimeter-sized gold wires we had been using and did a few quick and dirty experiments to see if anything would happen.

Something did. One of my then postdoctoral research associates, Rahela Gasparac, came running into my office, clutching a piece of paper with the results of the first test in her hand. The nanowires gave us a millionfold enhancement in sensitivity. For a moment we thought about heading out to celebrate. Then we realized we needed to repeat the experiments and turned around and went back to the lab. We wanted to be sure what we were seeing was real. Sure enough, it was, and we knew that we had a way to get at those 1,000 molecules that could allow us to diagnose disease.

Why did nanowires allow us to sense much lower concentrations of DNA? It was because their size has a profound influence on their shape. Shaved down to the nanoscale, these wires had spiky, little hills that did not appear in their larger cousins, whose bulk gave them a flat, smooth surface. A bait molecule on one side of a hill and one on the other side had more space around them than if they were crowded together on the flat, larger wire. Fluid could move more easily through that space, carrying with it the target molecules, and the bait and targets had much more opportunity to come in contact with one another.

These probes were good, but by hand our students could make only 10 of them a day. For real clinical use, we would need thousands of them. We turned, therefore, as so many scientists and engineers have done when they wanted to manufacture a whole lot of electrical devices, to silicon.

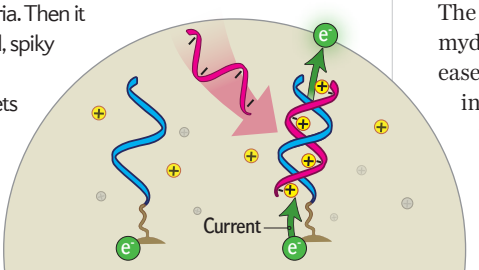
Chips made from silicon can be adorned with electrodes and mass-produced. We wanted to take the 10-nanometer hills featured on our nanowires—the spiky hills that enhanced sensitivity so much—and reproduce them on such a chip. After about six months, we found a good way to do this with a chemical process called electroplating. We could start with larger, microscale feature in the silicon and then use the plating chemistry to lay down finer layers of gold on top. Instead of growing nanowires, we learned it was quicker and easier to create a kind of gold dome with many spikes. By fixing bait molecules to different

SCIENTIFIC AMERICAN ONLINE Listen to Kelley and other nanoscientists describe their medical tests at ScientificAmerican.com/nov2015/get-small

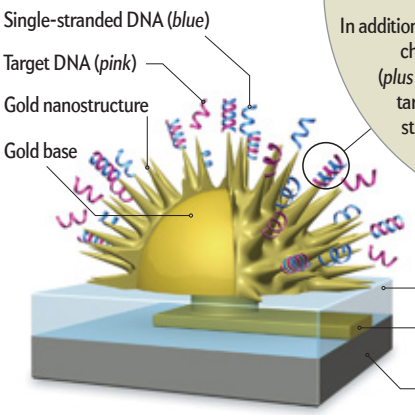
DIAGNOSTICS

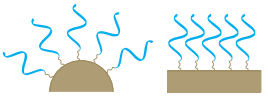
Small Device, Big Reaction

A nanosensor that detects the few molecules of bacterial DNA floating in a drop of blood needs three features. First, it needs "bait": molecules that attract DNA from specific bacteria. Then it needs to present the bait on a curved, spiky nanoscale surface, allowing enough space between the baits for the targets to reach them. Finally, the bait-target "hit" has to trigger an electric current that a sensor can detect.



In addition to the bait (*blue*), the test sample has positively charged particles of the metal ruthenium (*plus signs*). It is attracted to negatively charged target DNA (*pink*), and when this complex sticks to the bait and the gold nanowires, it pulls an electric current (*green arrows*) from the wires.





Curves on the nanoscale spread bait molecules farther apart, increasing the chance that target molecules will flow between them and stick. Larger-scale sensors have flat surfaces that crowd the bait too close together.

sides of the spikes, we mimicked the separation created by the hills in the original wires. And timing was key. If we let the plating process continue for a while, then the features would grow to an unusable size. But if we cut the time short, the features would only reach nanoscale and stop.

SCALING UP

OVER THE NEXT FEW YEARS we showed that we could use these detectors to analyze markers of infectious diseases caused by bacterial pathogens and that we could establish the presence or absence of the pathogen in 20 minutes. This turnaround time was important because for diagnostic testing to be successful in a doctor's office, the result would have to be returned during the course of a typical patient visit. Another feature of our approach is what we call "multiplexing"—the ability to search for multiple pathogens at one time. We were able to create multiple gold domes on the surface of our chips and attach a different type of bait molecule to each dome. This allowed us to drop a single blood sample on the chip and analyze it for many types of pathogens. Most other approaches can look for only a single type of pathogen DNA at a time. One of our most ambitious studies looked at 20 different bacteria at once, along with the DNA signals of five common types of antibiotic resistance. We were able to find them with 99 percent accuracy.

To try to get this technology out to doctors' offices, we started a company, Xagenic. The firm, for which I serve as chief technology officer, has taken our sensor chip, built a plastic cartridge around it and developed ways to include everything inside the cartridge that is needed to run a diagnostic test. The accuracy of these cartridges in finding chlamydia and gonorrhea, two sexually transmitted diseases, will be the focus of the clinical trials to start in 2016. The tests will involve physicians and their patients in 20 different medical offices. If this first trial stage is successful, we plan to submit the data to the U.S. Food and Drug Administration and ask for clearance to launch a commercial product.

We have a lot of competition from other promising nanoscale technologies. Some assays can home in on specific types of cancer with a new degree of accuracy. Chad A. Mirkin's group at Northwestern University, for instance, has developed gold nanospheres that react with cancer DNA even before the dangerous cells have formed tumors. David Walt of Tufts University has a system that counts how many disease marker molecules are present in a patient, which can be extremely useful for cancer diagnosis and monitoring. These approaches, however, are designed for use in testing labs rather than in a doctor's office.

Still other techniques do focus on on-the-spot diagnosis, and they are making their way toward mainstream medicine. Rustem Ismagilov's group at the California Institute of Technology has a wireless device, called the SlipChip, that allows DNA detection without the need for any type of cabled power. Earlier this year Samuel Sia of Columbia University and his colleagues reported in *Science Translational Medicine* on a tiny blood sampler that plugs into a cell phone and uses signals from antibodies to detect HIV.

I believe one or more of these technologies—or a completely different one that we do not yet know about—will eventually work well enough for everyday medical practice. At that point, reactions that take place at millionths or billionths of a meter will produce an outsize improvement in patient health. SA

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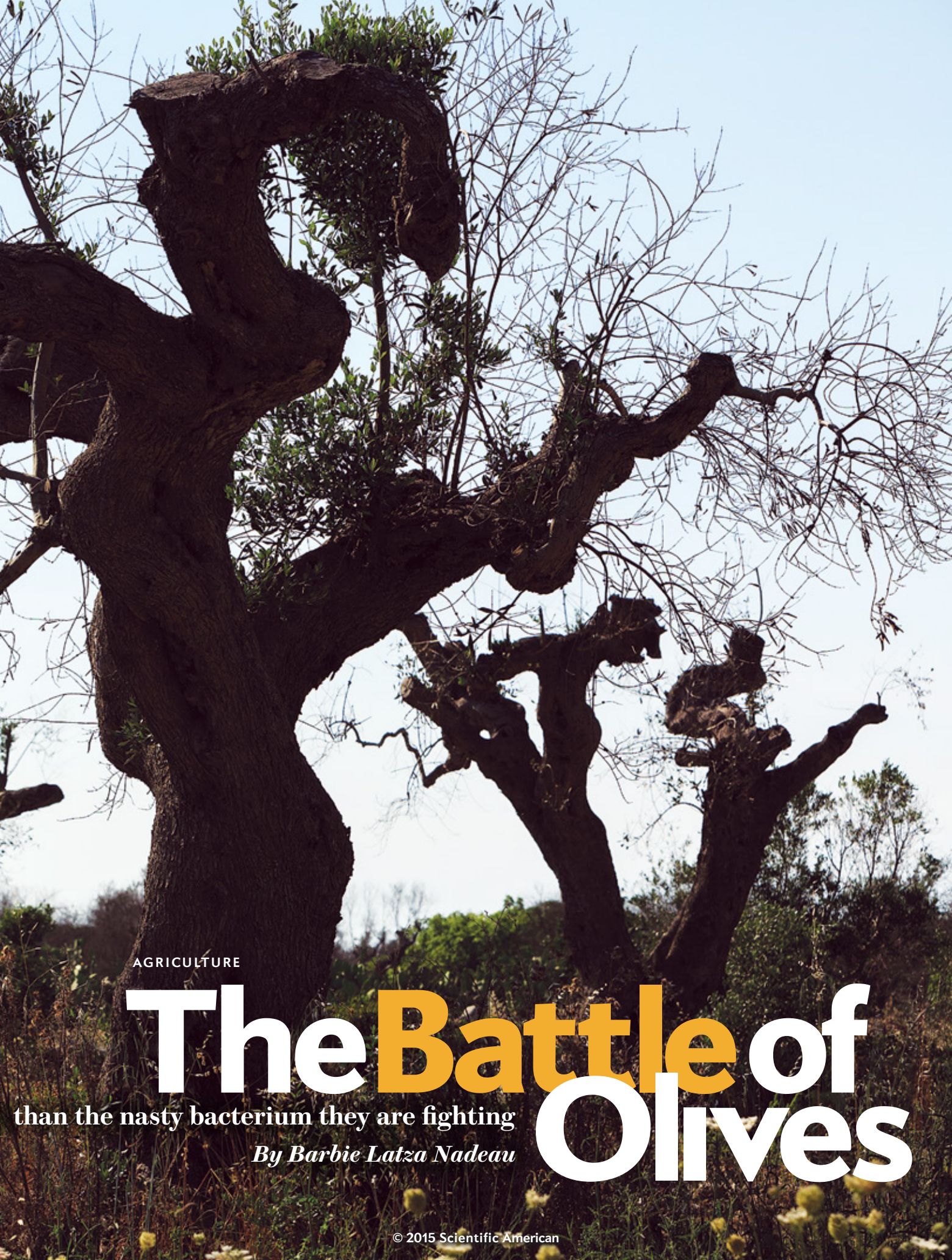
Illustration by Daisy Chung (insets) and George Retseck (nanosensor)

ANCIENT OLIVE TREES in southern Italy—limbs lopped off at the trunk by forestry officials in a vain attempt to stop a crippling bacterium from spreading—stand like ghosts in a combat zone.

Mistrust among growers and scientists may threaten Italy's olive groves more

Photographs by Pier Paolo Cito



AGRICULTURE

The Battle of Olives

than the nasty bacterium they are fighting

By Barbie Latza Nadeau

Barbie Latza Nadeau is an American journalist who has worked from Rome since 1996. She is author of *Angel Face: Sex, Murder and the Inside Story of Amanda Knox* (Beast Books, 2010).

The legendary olive trees of Puglia produce some of the finest oil in the world. Thousands of farm families have pressed the fruits for generations. The trees' twisted trunks—some radiocarbon-dated at more than 2,500 years old—are as fundamental to the landscape here as the castles and the sea. They have persisted through centuries of invasions, wars, droughts and depressions. No matter how bad things have ever gotten, the orchards have always provided promise for the future. That's why the spontaneous death of these trees, presumably by a foreign bacterium called *Xylella fastidiosa,* feels like a black plague. Carried by insects, the bacterium has swept through grove after grove.

Authorities have reacted with extreme measures. On July 7, Giuseppe Silletti, head of the Puglia division of the State Forestry Corps and special commissioner in charge of eradicating *Xylella,* ordered two dozen of his men to sweep into an area with several small groves near Oria at 5 A.M. to cut down more than 40 olive-laden trees. They arrived, chain saws blaring, without warning any of the owners or the local mayor, Cosimo Ferretti. More than 30 special armed police, generally dispatched to control riots, arrived with them to hold back the farmers and their families and neighbors. The owners watched in horror while the uniformed men massacred the ancient trees and yanked the gnarled roots from the ground, as if to symbolize the destruction of the region's deep-rooted heritage. Angry residents raised their fists and screamed, "Murderers!" Two women in their 50s—third-generation growers who were infuriated that their orchards were among those being razed—began to hit the police and were escorted away.

Such raids take place regularly now. In just two years since *Xylella* was first identified in the "heel" of Italy's "boot," known as the Salento, more than one million olive trees are dead, either withered by *Xylella* or killed by authorities trying to contain the disease's spread. But farmers and activists claim that the eradication is a farce because authorities offer no proof that the trees they destroy have the disease.

Science has an uneasy place in Italy. After all, this is the country where a court of law convicted six scientists and a government official of involuntary manslaughter for not predicting a

IN BRIEF

Insects are spreading a bacterium, *Xylella,* across olive groves in southern Italy. Authorities assume it is killing olive trees, and they are cutting down groves to try to prevent a wider infestation. **Uncertain about how** *Xylella* harms trees, scientists are reluctant to back the mass cuttings. Pesticides and better farm practices could possibly slow the disease. **Farmers say** scientists and officials are conspiring to needlessly destroy their groves, noting that the trees have survived scourges for more than 2,000 years. **If the disease** does spread and kill trees, olive oil prices could skyrocket, and the Mediterranean industry could wither.

RIOT POLICE near Oria (*opposite page*) stand ready to hold back angry grove owners who try to stop forestry personnel from cutting down trees thought to be infected with *Xylella.* Branches are burned near Lecce, center of the scourge (*above*).

2009 earthquake that struck L'Aquila. The scientists' convictions were eventually overturned by a higher court, but general mistrust of science is as Italian as olive oil itself. This past spring police raided offices at the main research center for *Xylella* in Bari, carrying out computers and boxes of files, apparently looking for a money trail or something else to prove that the presence of the bacterium is no accident. The tense relationship makes scientists reticent when they do not have ironclad data, which feeds a vicious cycle of suspicion.

It does not help that of the estimated 60 million olive trees in Puglia, only 30,000 are under surveillance for the disease by local researchers, yet hundreds of thousands are at risk of eradication. Trust is also missing because even the most learned experts, in Italy and around the world, do not know exactly how *Xylella* would kill an olive tree, which leaves open the troubling question of whether the bacterium is causing the scourge. It is present in many dead trees, but so far no one in authority has been able to connect events with a clear line.

Some research suggests *Xylella* stops water from flowing from the roots to the leaves, causing a tree to dry up. Other factors may contribute to actual death, however, such as common parasites and fungi, but scientists have yet to confirm or deny their roles. Part of the challenge is that when *Xylella* occurs in other plant species, it behaves differently, and its carriers can be more easily contained. Puglia is the first place *Xylella* has attacked olive trees, so there is no historical research. Some experts think it was introduced when a local garden center imported infected oleander plants from Costa Rica, where the same strain has been documented (there are three different strains).

Understanding if and how *Xylella* may have crossed over to olive trees would be a research triumph. But authorities are not waiting to find out. They do not test most dead trees because of lack of funding, as well as an overwhelming sense that they have to take action, now, to stop any further spread. The big fear is that the disease will advance northward, attacking the heart of Puglia's lucrative olive industry, which produces more olive oil than any other part of Italy. Neighboring countries also fear the

scourge will move up through the continent, perhaps even crossing over to grapes, almonds and cherries. Agriculture officials say Puglia will lose more than $225 million in olive oil production this year alone, but if the heart of the region succumbs to the bacterium, that figure could easily quadruple, driving up the price of oil worldwide.

One issue the scientific community agrees on is that even though *Xylella* is almost certainly carried by the meadow spittlebug, the widespread use of pesticides to stop the insect would cause serious collateral damage, poisoning the current olive crop and making the fruit and oil unfit for consumption for up to a decade. The chemicals would also kill surrounding plant life. Agronomists say, at best, pesticides could only be used, carefully, in underbrush during spittlebug nesting. That is why the scientific and agricultural communities in the European Union maintain that the only way to stop the disease is to create a buffer zone—to kill all the trees in a wide west-to-east swath between the dead and dying trees south of Lecce and those yet uninfected to the north. If *Xylella* is found on a single tree anywhere near the buffer zone, every tree within 100 meters (328 feet) is spray-painted with a red X that drips like blood down the thick, craggy bark, to signify that it must also be destroyed. Then, without notice, the forestry corps agents arrive with their chain saws.

OLIVE FARMERS Cosima (*at left in image above*) and Angela Tommaselli despair over their severed, uprooted trees in Oria. Another owner in Trepuzzi (*opposite page*) shows young, healthy olives as proof that his trees are not sick.

The farmers, who know the groves best, insist that many of the marked trees are healthy and do not need to be sacrificed. Scientists on testing trips around Puglia are scrambling to improve the data. But the men with chain saws are one step ahead of them.

DEATH TO INSECTS AND TREES

DONATO BOSCIA, a virologist in charge of the Bari unit at the National Research Council of Italy's Institute for Sustainable Plant Protection, is the leading scientist on the front line of the ill-informed battle. He maintains an awkward balance between directing research and placating a population that views almost everything he does with skepticism or contempt. He is also the man who first identified the bacterium in 2013, in olive groves owned by his father-in-law south of Lecce. "I knew this was something big," he told me at his greenhouse laboratory in Bari, as he recalled how his father-in-law summoned him to his groves to show him "something wrong." "What I didn't know then was that by now, almost two years later, we still wouldn't have a cure or that we would have faced so many obstacles and lost so much valuable time trying to contain the spread."

Boscia is referring to what has become a frustrating game of resistance to even the most basic prevention suggestions. He is one of several scientists under judicial investigation for potential wrongdoing in handling the aftermath of the outbreak. Yet he chooses to forge ahead, playing tug-of-war between what should be done to save the trees and what will be achievable in reality.

For instance, because the widespread use of pesticides to obliterate the spittlebugs is not a viable option, he says that good farming practices are crucial to reducing the bug population, including clearing the underbrush of weeds where bugs nest and very controlled spot spraying of insecticides when the spittlebugs are on the canopy of trees. But many farmers refuse to even try spot spraying, he says, out of fear they won't be able to use their oil. "There is no one weapon to fight this bacterium, so we need to implement an integrated plan aimed to control the [spread]," he says, referring to both better farming practices to thin out the bugs and cutting trees in the buffer zone to stop the bugs from advancing geographically. "But even that won't work unless everyone follows it."

One of the few certainties in this drama is that insects infected with *Xylella* transmit the bacterium as they move from tree to tree and puncture the trees' xylem to feed (the xylem is plant tissue that carries nutrients). The presumed enemy, the meadow spittlebug, is abundant in the region. But cicadas, whose grinding love songs are almost deafening throughout Puglia's olive groves, may also spread the bacterium. At the time of this writing, however, cicadas had not been systematically examined, because they are nearly impossible to catch in great enough numbers for clinical analysis.

Even though testing shows *Xylella* is present in many dead trees, local farmers and activists are angered because so many trees go untested. They want all the groves under surveillance. According to a report sent to the E.U. by Italy's agricultural ministry in July, just 33,600 inspections out of more than 60 million trees have been conducted across Italy since the initial outbreak. Hundreds of agents from Italy's National Research Council and the State Forestry Corps have monitored more than 152,000 acres of olive groves, but so much more area is involved that no one can yet say whether the disease is endemic to the region.

Technicians take samples to one of two labs for testing. Most of the samples from the Salento go to the agricultural research center CRFSA "Basile-Caramia" in Locorotondo, run by Vito Nicola Savino. He told SCIENTIFIC AMERICAN that his small staff has had to delay other projects to concentrate on testing and research

Scientists lack hard data about the bacterium's spread, so they tend to stay silent, which many olive growers interpret as a cover-up. Conspiracy theories abound.

PLAN TO CONTAIN *Xylella* has four zones. Infected: Olive trees are given up for lost. Eradication: Trees are cut down when the bacterium is found. Buffer: All trees, infected or not, are destroyed to block the disease's spread. Security: Trees are only monitored for now.

SOURCE: *OFFICIAL BULLETIN OF THE PUGLIA REGION [ITALY]*, NO. 39, MARCH 19, 2015

dedicated to *Xylella*. His hope is that the global scientific community will soon start to study the dying trees in situ, in a proposed open-air lab, to better understand the disease's devastating effects. That project was green-lighted by the region's previous governor but then largely forgotten when he lost his job in an election this past spring. "We have the opportunity here to be a world leader in the study of this phenomenon," Savino says. "We have a new occurrence of *Xylella* affecting a species in a way that is completely unexpected."

He also believes that eradication is fundamental because trying to stop the spread by insects (called vectors) is proving impossible without widespread pesticide use. In many ways, the scientists, backed by the E.U., have come up with a prescription of extensive cutting without knowing all the facts. Authorities are going on faith that if they get rid of trees in the buffer zone, the spittlebugs will have nowhere to feed and potentially die off, or at least they will stay contained in the infected area. Savino has signed on. "We have to get rid of the infected plants before we can possibly hope to destroy the vectors," he maintains. "There is no other way to win this battle."

CONSPIRACY THEORIES

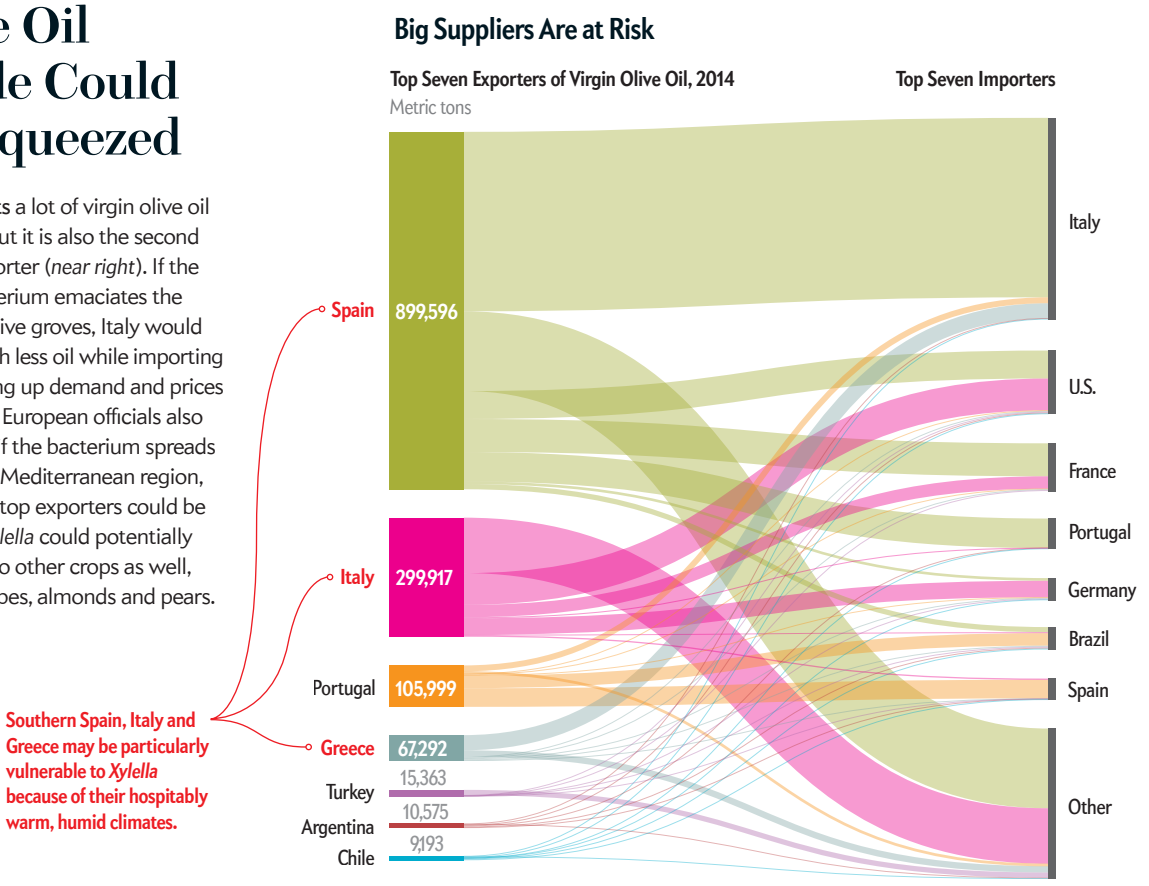
BECAUSE THE ERADICATION AREA is where the bulk of the region's monumental trees have thrived for centuries, farmers strongly oppose the plan, believing that authorities are unnecessarily panicking and that there must surely be a better way. How, they wonder, could trees that have survived so long be wiped out entirely? Why, if *Xylella* has been contained without drastic eradication in other parts of the world when it attacked different plant species such as grapes in California, can it not be effectively contained in olive groves in Puglia? When the bacterium caused Pierce's disease in grapes in California, Florida and Texas, pesticides, radical pruning and crop replacement with *Xylella*-resistant varieties successfully contained the disease. Although it might take a decade or more to establish productive, *Xylella*-resistant olive trees, the growers note that that is almost overnight in an industry that has flourished for two millennia.

Because scientists cannot answer such basic questions, the gap between the opposing sides widens. Hard data are scarce, so the scientists and local authorities tend to stay silent, which many growers interpret as a cover-up for ulterior motives. Ask anyone in Puglia what they think of *Xylella,* and you get a range of conspiracy theories: that the American firm Monsanto introduced a genetically modified strain of the bacterium in Puglia so

Map by Terra Carta

Olive Oil Trade Could Be Squeezed

Italy imports a lot of virgin olive oil (*far right*), but it is also the second largest exporter (*near right*). If the *Xylella* bacterium emaciates the country's olive groves, Italy would export much less oil while importing more, driving up demand and prices worldwide. European officials also worry that if the bacterium spreads around the Mediterranean region, the world's top exporters could be crippled. *Xylella* could potentially cross over to other crops as well, such as grapes, almonds and pears.



it could sweep in with a cure; that a British land developer with dreams of turning Puglia into a golf Mecca has used sinister means to clear the land so he can buy it cheap. None of this can be proved, but neither can the prevailing scientific theory that *Xylella* was introduced in a shipment of exotic plants from Costa Rica.

The lack of cooperation worries the rest of the continent. This past January the European Food Safety Authority issued an apocalyptic warning: "*X. fastidiosa* may affect several crops in Europe, such as citrus, grapevine and stone fruits (almond, peach, plum), but also several tree and ornamental plants, for example, oak, sycamore and oleander.... The probability of establishment, following an entry of *X. fastidiosa,* is rated as very likely." The agency supports the plans for a buffer zone but calls into question the effectiveness of eradication without mandating proper farming practices, including spot pesticide use.

Some steps are starting to happen—ironically, in areas south of Lecce, which Boscia describes as "hit by an ecological bomb." The farmers there have been left to decide how to protect the few trees that remain healthy among the stumps that stand like remains of deceased soldiers in a battlefield, hoping that those ghosts will miraculously come back to life.

The farmers there are experimenting with organic treatments, coupled with age-old traditions, including grafting limbs of healthy trees onto those that are sick. It is too early to know if they might succeed. This is also the place where Savino would have implemented his ambitious plan to build an open-air lab to study the effects of the disease. In a brief moment of optimism this past spring, the local government pledged €2 million to build an international research center for it, but the elections changed that.

DISTRUST IN SCIENCE

NORTH OF THE AFFECTED AREA, in the buffer zone, talk is more defiant. Standing in his grove, farmer Pasquale Spina tells me in angry tones that the disease is a figment of the scientists' imagination, as he strokes new green stalks sprouting from a stump cut under the eradication plan. "History tells you how difficult it is to kill an olive tree," he says, pointing to ancient trees nearby that are scarred from lightning strikes and parasites. "The trees are sick maybe, yes, but they are sick for other reasons, not *Xylella*. You don't have to kill these trees that have survived everything that came at them. Why now, when we have such scientific advancements, do 1,000-year-old trees have to die like this?"

That, of course, is the billion-dollar question. There is perhaps no one more versed in *Xylella* than Alexander Purcell, a professor emeritus at the University of California, Berkeley, who has published extensive research on the impact of the bacterium on agricultural crops. He believes *Xylella* is responsible for the death of the trees south of Lecce, having visited the area after the outbreak was first confirmed. He recalls the moment when a spittlebug landed on the windshield of a car he was riding in and stayed

SOURCE: DESA/UNSD, UNITED NATIONS COMTRADE DATABASE *http://comtrade.un.org*

SCIENTIFIC AMERICAN ONLINE To watch a video of Italian olive growers objecting to tree cutting, see ScientificAmerican.com/nov2015/nadeau

Graphic by Daisy Chung

VIROLOGIST Donato Boscia inspects an olive leaf in his lab in Bari. He identified the suspicious *Xylella* bacterium and leads Italian research for a cure, even as officials investigate him for potentially mishandling the disease outbreak.

there for miles, proving how easy it is for potentially infected vectors to move. Hence, he is not a fan of the full-eradication plan. The best approach, he insists, is a combination of limited pesticide use and good farming practices in addition to culling infected groves. "There are a lot of things about *Xylella* that we don't understand," he says. "But it is going to take a cascade of control efforts to beat this. No single silver bullet is going to do it."

Purcell says the Italian scientific community has a great responsibility to study the effects of *Xylella* on a new crop, but he admits that unless there is more transparency and trust, the effects on groves—as well as the lost opportunities for research—could be devastating. "If diseased tree removal is such a difficult obstacle to overcome—maybe impossible in rural Italy—how hard will it be to overlay area-wide insecticide use?" he asks. "Only the combination might have any effect." He adds that experts would know if the approach works only after trying it for several years. "Do you think that the Italian citizenry will support this?" he asks.

Maybe not, but Purcell believes the experts should try. The economic fallout of this new epidemic could be striking, he notes. And the cultural importance of the olive tree in the Mediterranean "gives this disease an impact I haven't experienced with grapes, citrus and other crops that were hit suddenly with *Xylella*. Many ancient trees along the Mediterranean have survived centuries with little care," Purcell adds.

Purcell does not have a concrete answer for the larger issue, either: the disease's sudden appearance and devastating effects. "Why in Europe now, when the pathogen has been living in a huge diversity of plants in the Americas for so long?" he wonders.

DOUBT STALLS A CURE

THE TREE OWNERS wonder, too. Scientists will have to overcome their reluctance to talk and conquer the prevalence of conspiracy theories to gain trust and guide tree owners out of the crisis. Open dissemination of reliable information, even if it is not conclusive, is key. But clarity can be difficult to find. Francesca Mandese, a reporter for the newspaper *Corriere del Mezzogiorno* has been following the spread of *Xylella* since the first olive leaves showed symptoms. She says her biggest challenge is finding the balance between the scientific community's lack of transparency and the activists' zeal. "It leaves me perplexed that no one seems to be certain about anything," she says. "Instead it is always 'maybe' and 'probably.' In the end, you can't just destroy thousands of trees without being certain."

That doubt also causes knee-jerk reactions by some farmers. Out of fear that their trees will be culled, many growers now try to hide symptoms of the drying effects of *Xylella*. When they see so much as a dead branch on their trees, they immediately prune the limb or, in some cases, burn the tree entirely before anyone can alert inspectors.

Purcell suggests that the best hope for growers in Puglia is to harness recent advancements in genetic engineering and start over with new olive tree varieties that are *Xylella*-resistant. It has taken 10 years or more for that approach to produce decent grapevines in California, and he says success could take twice as long in Puglia. "The cost in time and money will be enormous. But it is still better to start now instead of later. The economic and ecological payoffs in breeding are always manyfold greater than their costs."

Purcell's words may not inspire the people of Puglia. What they know for certain is that *Xylella* has not affected olive oil whatsoever, simply because the sick trees do not produce olives. Angela Amico is a proprietor of the well-known Cibus restaurant here. She and her husband produce olive oil for their customers from trees that may soon be painted in red for eradication, even though she says her trees are more fruitful now than they have been for a decade. She has faith that the trees can survive on their own, just like they have done for millennia. "My olives have never looked better," she says. "What more proof do I need that my trees are healthy?" SA

MORE TO EXPLORE

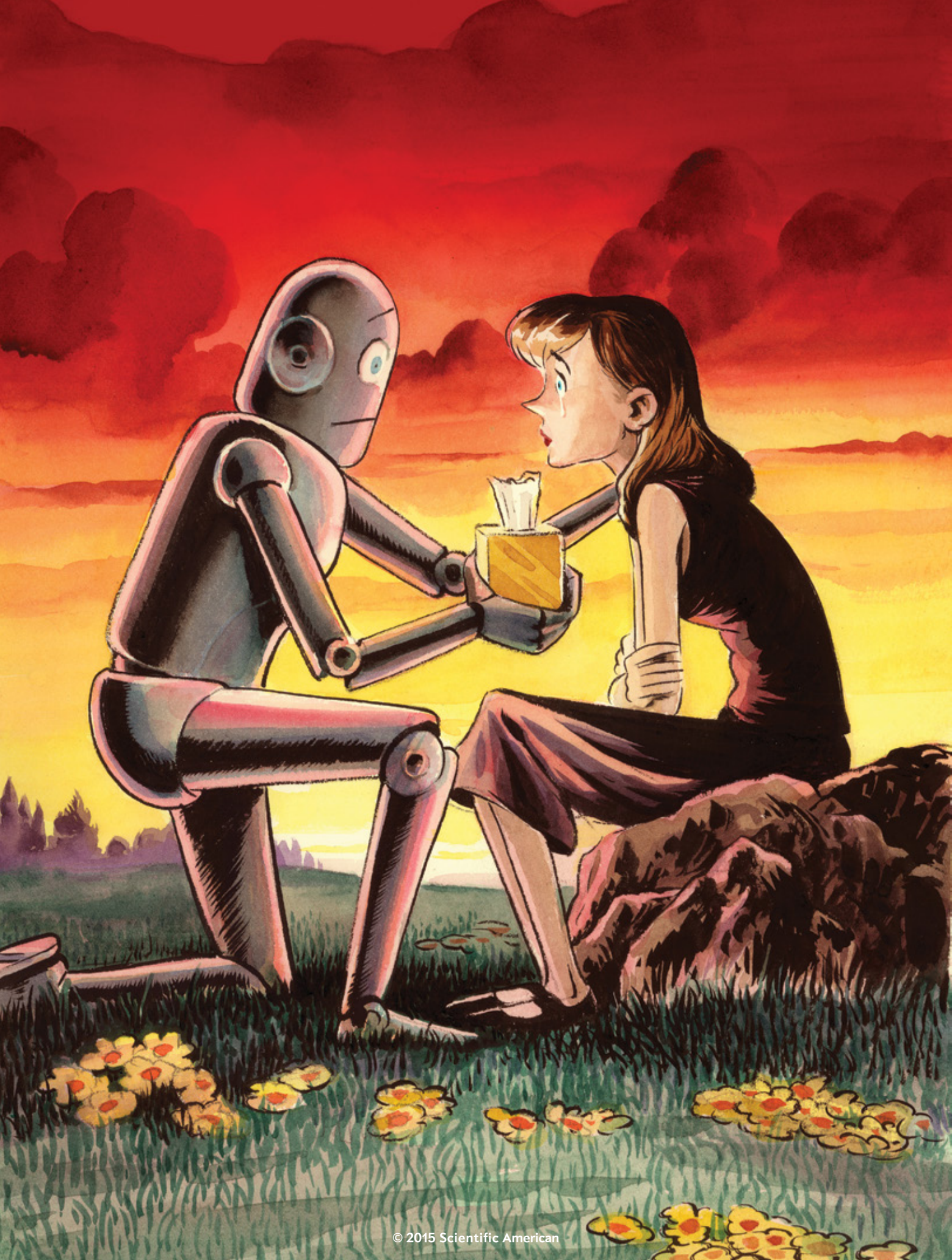
Identification of DNA Sequences Related to *Xylella fastidiosa* in Oleander, Almond and Olive Trees Exhibiting Leaf Scorch Symptoms in Apulia. M. Saponari et al. in *Journal of Plant Pathology*, Vol. 95, No. 3; 2013.

Ongoing coverage of the *Xylella* drama can be found at http://xylellacodiro.blogspot.it

FROM OUR ARCHIVES

Super Dirt. Richard Conniff; September 2013.

scientificamerican.com/magazine/sa



TECHNOLOGY

ROBOTS WITH HEART

Before we can share our lives with machines, we must teach them to understand and mimic human emotion

By Pascale Fung

"Sorry, I didn't hear you."

This may be the first empathetic utterance by a commercial machine. In the late 1990s the Boston company SpeechWorks International began supplying companies with customer-service software programmed to use this phrase and others. In the years since, we have become accustomed to talking to machines. Nearly every call to a customer-service line begins with a conversation with a robot. Hundreds of millions of people carry an intelligent personal assistant around in their pocket. We can ask Siri and other such assistants to find restaurants, call our friends or look for a song to play. They are capable of simulating eerily human behavior. (Human: "Siri, do you love me?" Siri: "I am not capable of love.")

IN BRIEF

As we interact more frequently with voice- and gesture-controlled machines, we will expect them to recognize emotions and understand high-level communication features such as humor, sarcasm and intention.

To make such communication possible, we need to endow machines with an empathy module—a software system that can extract emotional cues from human speech and behavior and can guide the response of a robot accordingly.

Research on empathetic robots is in its infancy, but scientists are already using signal-processing techniques, machine-learning algorithms and sentiment-analysis tools to build virtual robots that can "understand" human emotion.

Illustration by Zohar Lazar

Pascale Fung is a professor of electronic and computer engineering at the Hong Kong University of Science and Technology. She was elected a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and a fellow of the International Speech Communication Association (ISCA) for her contributions to human-machine interactions.

But machines do not always respond the way we would like them to. Speech-recognition software makes mistakes. Machines often fail to understand intention. They do not get emotion and humor, sarcasm and irony. If in the future we are going to spend more time interacting with machines—and we are, whether they are intelligent vacuum cleaners or robotic humanoid nurses—we need them to do more than understand the words we are saying: we need them to *get* us. We need them, in other words, to "understand" and share human emotion—to possess empathy.

In my laboratory at the Hong Kong University of Science and Technology, we are developing such machines. Empathetic robots can be of great help to society. They will not be mere assistants—they will be companions. They will be friendly and warm, anticipating our physical and emotional needs. They will learn from their interactions with humans. They will make our lives better and our jobs more efficient. They will apologize for their mistakes and ask for permission before proceeding. They will take care of the elderly and teach our children. They might even save your life in critical situations while sacrificing themselves in the process—an act of ultimate empathy.

Some robots that mimic emotion are already on the market—including Pepper, a small humanoid companion built by the French firm Aldebaran Robotics for the Japanese company Softbank Mobile, and Jibo, a six-pound desktop personal-assistant robot designed by a group of engineers that included Roberto Pieraccini, former director of dialog technologies at SpeechWorks. The field of empathetic robotics is still in its steam-engine days, but the tools and algorithms that will dramatically improve these machines are emerging.

THE EMPATHY MODULE

I BECAME INTERESTED IN BUILDING empathetic robots six years ago, when my research group designed the first Chinese equivalent of Siri. I found it fascinating how naturally users developed emotional reactions to personal-assistant systems—and how frustrated they became when their machines failed to understand what they were trying to communicate. I realized that the key to building machines that could understand human emotion were speech-recognition algorithms like those I had spent my 25-year career developing.

Any intelligent machine is, at its core, a software system consisting of modules, each one a program that performs a single task. An intelligent robot could have one module for processing human speech, one for recognizing objects in images captured by its video camera, and so on. An empathetic robot has a heart, and that heart is a piece of software called the empathy module. An empathy module analyzes facial cues, acoustic markers in speech and the content of speech itself to read human emotion and tell the robot how to respond.

When two people communicate with each other, they automatically use a variety of cues to understand the other person's emotional state—they interpret facial gestures and body language; they perceive changes in tone of voice; they understand the content of speech. Building an empathy module is a matter of identifying those characteristics of human communication that machines can use to recognize emotion and then training algorithms to spot them.

When my research group set out to train machines to detect emotion in speech, we decided to teach machines to recognize fundamental acoustic features of speech in addition to the meaning of the words themselves because this is how humans do it. We rarely think of it in these terms, but human communication is signal processing. Our brain detects emotion in a person's voice by paying attention to acoustic cues that signal stress, joy, fear, anger, disgust, and so on. When we are cheerful, we talk faster, and the pitch of our voice rises. When we are stressed, our voices become flat and "dry." Using signal-processing techniques, computers can detect these cues, just as a polygraph picks up blood pressure, pulse and skin conductivity. To detect stress, we used supervised learning to train machine-learning algorithms to recognize sonic cues that correlate with stress.

A brief recording of human speech might contain only a few words, but we can extract vast amounts of signal-processing data from the tone of voice. We started by teaching machines to recognize negative stress (distress) in speech samples from students at my institution, which students have given the nickname "Hong Kong University of Stress and Tension." We built the first-ever multilingual corpus of natural stress emotion in English, Mandarin and Cantonese by asking students 12 increasingly stressful questions. By the time we had collected about 10 hours of data, our algorithms could recognize stress accurately 70 percent of the time—remarkably similar to human listeners.

While we were doing this work, another team within my group was training machines to recognize mood in music by analyzing sonic features alone (that is, without paying attention to lyrics). Mood, as opposed to emotion, is an ambiance that lasts over the duration of the music played. This team started by collecting 5,000 pieces of music from all genres in major European and Asian languages. A few hundred of those pieces had already been classified into 14 mood categories by musicologists.

We electronically extracted some 1,000 fundamental signal attributes from each song—acoustic parameters such as energy, fundamental frequency, harmonics, and so on—and then used the labeled music to train 14 different software "classifiers," each one responsible for determining whether a piece of music belongs to a specific mood. For example, one classifier listens to only happy music, and another listens only for melancholy music. The 14 classifiers work together, building on one another's guesses. If a "happy" classifier mistakenly finds a melancholic song to be happy, then in the next round of relearning, this classifier will be retrained. At each round, the weakest classifier is retrained, and the overall system is boosted. In this manner, the machine listens to many pieces of music

SCIENTIFIC AMERICAN ONLINE See a video of an empathetic robot prototype at ScientificAmerican.com/nov2015/robots

and learns which one belongs to which mood. In time, it is able to tell the mood of any piece of music by just listening to the audio, like most of us do. Based on this research, former students and I started a company called Ivo Technologies to build empathetic machines for people to use at home. The first product, Moodbox, will be a smart home infotainment center that controls the music and lighting in each room and responds to user emotions.

UNDERSTANDING INTENT

TO UNDERSTAND HUMOR, sarcasm, irony and other high-level communication attributes, a machine will need to do more than recognize emotion from acoustic features. It will also need to understand the underlying meaning of speech and compare the content with the emotion with which it was delivered.

Researchers have been developing advanced speech recognition using data gathered from humans since the 1980s, and today the technology is quite mature. But there is a vast difference between transcribing speech and *understanding* it.

Think of the chain of cognitive, neurological and muscular events that occurs when one person speaks to another: one person formulates her thoughts, chooses her words and speaks, and then the listener decodes the message. The speech chain between humans and machine goes like this: speech waves are converted into digital form and then into parameters. Speech-recognition software turns these parameters into words, and a semantic decoder transforms words into meaning.

When we began our research on empathetic robots, we realized that algorithms similar to those that extract user sentiment from online comments could help us analyze emotion in speech. These machine-learning algorithms look for telltale cues in the content. Key words such as "sorrow" and "fear" suggest loneliness. Repeated use of telltale colloquial words ("c'mon," for example) can reveal that a song is energetic. We also analyze information about the style of speech. Are a person's answers certain and clear or hesitant, peppered with pauses and hedged words? Are the responses elaborate and detailed or short and curt?

In our research on mood recognition in music, we have trained algorithms to mine lyrics for emotional cues. Instead of extracting audio signatures of each piece of music, we pulled strings of words from the song's lyrics and fed them to individual classifiers, each one responsible for determining whether this string of words conveys any of the 14 moods. Such strings of words are called *n*-grams. In addition to word strings, we also used part-of-speech tags of these words as part of the lyrics "signature" for mood classification. Computers can use *n*-grams and part-of-speech tags to form statistical approximations of grammatical rules in any language; these rules help programs such as Siri recognize the speech and software such as Google Translate convert text into another language.

Once a machine can understand the content of speech, it can compare that content with the way it is delivered. If a person sighs and says, "I'm so glad I have to work all weekend," an algorithm can detect the mismatch between the emotion cues and the content of the statement and calculate the probability that the speaker is being sarcastic. Similarly, a machine that can understand emotion and speech content can pair that information with other inputs to detect more complex intentions. If someone says, "I'm hungry," a robot can determine the best response based on its location, time of day and the historical preferences of its user, along with other parameters. If the robot and its user are at home and it is almost lunchtime, the robot might know to respond: "Would you like me to make you a sandwich?" If the robot and its user are traveling, the machine might respond: "Would you like for me to look for restaurants?"

ZARA THE SUPERGIRL

AT THE BEGINNING of this year students and postdoctoral researchers in my lab began pulling all our various speech-recognition and emotion-recognition modules together into a prototype empathetic machine we call Zara the Supergirl. It took hundreds of hours of data to train Zara, but today the program runs on a single desktop computer. For the moment, she is a virtual robot, represented on a screen by a cartoon character.

When you begin a conversation with Zara, she says, "Please wait while I analyze your face"; Zara's algorithms study images captured by the computer's webcam to determine your gender and ethnicity. She will then guess which language you speak (Zara understands English and Mandarin and is learning French) and ask you a few questions in your native tongue. *What is your earliest memory? Tell me about your mother. How was your last vacation? Tell me a story with a woman, a dog and a tree.* Through this process, based on your facial expressions, the acoustic features of your voice and the content of your responses, Zara will reply in ways that mimic empathy. After five minutes of conversation, Zara will try to guess your personality and ask you about your attitudes toward empathetic machines. This is a way for us to gather feedback from people on their interactions with early empathetic robots.

Zara is a prototype, but because she is based on machine-learning algorithms, she will get "smarter" and more empathetic as she interacts with more people and gathers more data. Right now her database of knowledge is based only on interactions with graduate students in my lab. Next year we plan to give Zara a body by installing her in a humanoid robot.

It would be premature to say that the age of friendly robots has arrived. We are only beginning to develop the most basic tools that emotionally intelligent robots would need. And when Zara's descendants begin arriving on the market, we should not expect them to be perfect. In fact, I have come to believe that focusing on making machines perfectly accurate and efficient misses the point. The important thing is that our machines become more human, even if they are flawed. After all, that is how humans work. If we do this right, empathetic machines will not be the robot overlords that some people fear. They will be our caregivers, our teachers and our friends. SA

MORE TO EXPLORE

A Multilingual Database of Natural Stress Emotion. Xin Zuo, Tian Li and Pascale Fung. Presented at the Eighth International Conference on Language Resources and Evaluation (LREC 2012), Istanbul, May 21–27, 2012.

Multimodal Music Emotion Classification using AdaBoost with Decision Stumps. Dan Su, P. Fung and N. Auguin. Presented at the 2013 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP 2013), Vancouver, May 26–31, 2013.

FROM OUR ARCHIVES

Robot Be Good. Michael Anderson and Susan Leigh Anderson; October 2010.

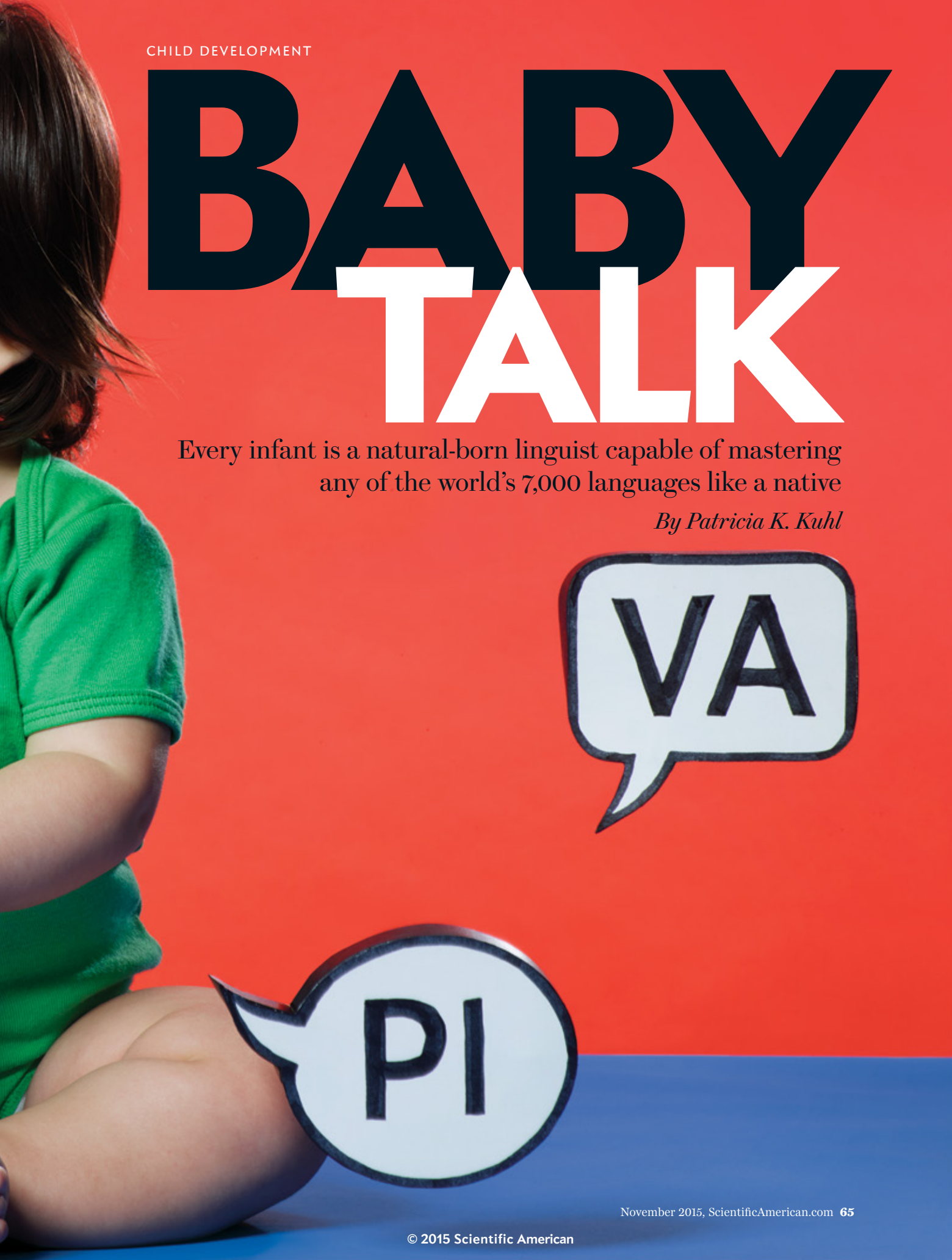
scientificamerican.com/magazine/sa

Photographs by Hannah Whitaker

BABY TALK

Every infant is a natural-born linguist capable of mastering any of the world's 7,000 languages like a native

By Patricia K. Kuhl



Patricia K. Kuhl is Bezos Family Foundation Endowed Chair for Early Childhood Learning, co-director of the University of Washington Institute for Learning & Brain Sciences, and director of the LIFE Center, an NSF-funded Science of Learning Center.

AN INFANT CHILD POSSESSES AN AMAZING, AND FLEETING, GIFT: THE ABILITY to master a language quickly. At six months, the child can learn the sounds that make up English words and, if also exposed to Quechua and Tagalog, he or she can pick up the unique acoustic properties of those languages, too. By age three, a toddler can converse with a parent, a playmate or a stranger.

I still marvel, after four decades of studying child development, how a child can go from random babbling to speaking fully articulated words and sentences just a few years later—a mastery that occurs more quickly than any complex skill acquired during the course of a lifetime. Only in the past few years have neuroscientists begun to get a picture of what is happening in a baby's brain during this learning process that takes the child from gurgling newborn to a wonderfully engaging youngster.

At birth, the infant brain can perceive the full set of 800 or so sounds, called phonemes, that can be strung together to form all the words in every language of the world. During the second half of the first year, our research shows, a mysterious door opens in the child's brain. He or she enters a "sensitive period," as neuroscientists call it, during which the infant brain is ready to receive the first basic lessons in the magic of language.

The time when a youngster's brain is most open to learning the sounds of a native tongue begins at six months for vowels and at nine months for consonants. It appears that the sensitive period lasts for only a few months but is extended for children exposed to sounds of a second language. A child can still pick up a second language with a fair degree of fluency until age seven.

The built-in capacity for language is not by itself enough to get a baby past the first utterances of "Mama" and "Dada." Gaining mastery of the most important of all social skills is helped along by countless hours listening to parents speak the silly vernacular of "parentese." Its exaggerated inflections—"You're a preettee babbee"—serve the unfrivolous purpose of furnishing daily lessons in the intonations and cadences of the baby's native tongue. Our work puts to rest the age-old debates about whether genes or the environment prevails during early language development. They both play starring roles.

Knowledge of early language development has now reached a level of sophistication that is enabling psychologists and physicians to fashion new tools to help children with learning difficulties. Studies have begun to lay the groundwork for using recordings of brain waves to determine whether a child's language abilities are developing normally or whether an infant may be at risk for autism, attention deficit or other disorders. One day a routine visit to the pediatrician may involve a baby brain examination, along with vaccinations for measles, mumps and rubella.

THE STATISTICS OF BABY TALK

THE REASON WE CAN CONTEMPLATE a test for language development is that we have begun to understand how babies absorb language with seeming ease. My laboratory and others have shown that infants use two distinct learning mechanisms at the earliest stages of language acquisition: one that recognizes sound through mental computation and another that requires intense social immersion.

To learn to speak, infants have to know which phonemes make up the words they hear all around them. They need to dis-

IN BRIEF

A baby's brain enters a "sensitive" period at the age of six months—a time when a child is best able to perceive the sounds of a language or two in preparation for developing the fluent tones and cadences of a native speaker.

The built-in capacity for language does not on its own propel the child past the first utterances of "Mama" and "Dada." To learn this most important of social skills requires that a baby pay careful attention to countless hours of parent-speak.

Insights from research into early language acquisition have reached a degree of sophistication that has enabled neuroscientists to contemplate the possibility of using brain recordings to test whether a child's brain is developing as it should.

CLOTHING AND PROP STYLING BY EMILY MULLIN *Hello Artists*; MODELS FROM ABRAMS

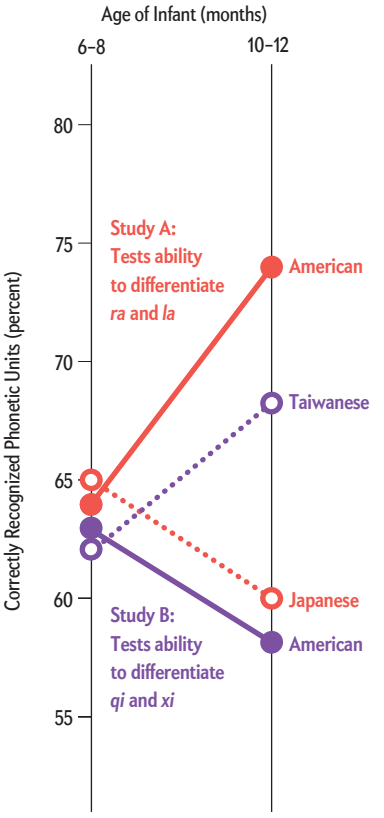
criminate which 40 or so, out of all 800, phonemes they need to learn to speak words in their own language. This task requires detecting subtle differences in spoken sound. A change in a single consonant can alter the meaning of a word—"bat" to "pat," for instance. And a simple vowel like "ah" varies widely when spoken by different people at different speaking rates and in different contexts—"Bach" versus "rock." Extreme variation in phonemes is why Apple's Siri still does not work flawlessly.

My work and that of Jessica Maye, then at Northwestern University, and her colleagues have shown that statistical patterns—the frequency with which sounds occur—play a critical role in helping infants learn which phonemes are most important. Children between eight and 10 months of age still do not understand spoken words. Yet they are highly sensitive to how often phonemes occur—what statisticians call distributional frequencies. The most important phonemes in a given language are the ones spoken most. In English, for example, the "r" and "l" sounds are quite frequent. They appear in words such as "rake" and "read" and "lake" and "lead." In Japan, the English-like "r" and "l" also occur but not as often. Instead the Japanese "r" sound is common but is rarely found in English. (The Japanese word "raamen" sounds like "laamen" to American ears because the Japanese "r" is midway between the American "r" and "l.")

SENSITIVE PERIOD

Culture-Bound Listening

Between six and eight months, infants can discriminate phonetic units, such as "ra" and "la," regardless of the culture in which they are raised. By 10 months, this window begins to close, and infants show the first signs of becoming culture-bound listeners. In a study conducted in Tokyo and Seattle, Japanese infants' abilities to hear the difference between "ra" and "la" declined, whereas American infants' capacity to perceive these sounds increased over that period (*red lines*). A study in Taipei and Seattle showed that Taiwanese infants' abilities to hear the difference between "qi" and "xi" grew; in contrast, American infants' capacity diminished (*purple lines*). Infants instinctually do exactly what they need to do to advance language skills.



The statistical frequency of particular sounds affects the infant brain. In one study of infants in Seattle and Stockholm, we monitored their perception of vowel sounds at six months and demonstrated that each group had already begun to focus in on the vowels spoken in their native language. The culture of the spoken word had already pervaded and affected how the baby's brain perceived sounds.

What exactly was going on here? Maye has shown that the brain at this age has the requisite plasticity to change how infants perceive sounds. A Japanese baby who hears sounds from English learns to distinguish the "r" and the "l" in the way they are used in the U.S. And a baby being raised among native English speakers could likewise pick up the characteristic sounds of Japanese. It appears that learning sounds in the second half of the first year establishes connections in the brain for one's native tongue but not for other languages, unless a child is exposed to multiple languages during that period.

Later in childhood, and particularly as an adult, listening to a new language does not produce such dramatic results—a traveler to France or Japan can hear the statistical distributions of sounds from another language, but the brain is not altered by the experience. That is why it is so difficult to pick up a second language later on.

A second form of statistical learning lets infants recognize whole words. As adults, we can distinguish where one word ends and the next begins. But the ability to isolate words from the stream of speech requires complex mental processing. Spoken speech arrives at the ear as a continuous stream of sound that lacks the separations found between written words.

Jenny Saffran, now at the University of Wisconsin–Madison, and her colleagues—Richard Aslin of the University of Rochester and Elissa Newport, now at Georgetown University—were the first to discover that a baby uses statistical learning to grasp the sounds of whole words. In the mid-1990s Saffran's group published evidence that eight-month-old infants can learn wordlike units based on the probability that one syllable follows another. Take the phrase "pretty baby." The syllable "pre" is more likely to be heard with "ty" than to accompany another syllable like "ba."

In the experiment, Saffran had babies listen to streams of computer-synthesized nonsense words that contained syllables, some of which occurred together more often than others. The babies' ability to focus on syllables that coincide in the made-up language let them identify likely words.

The discovery of babies' statistical-learning abilities in the 1990s generated a great deal of excitement because it offered a theory of language learning beyond the prevailing idea that a child learns only because of parental conditioning and affirmations of whether a word is right or wrong. Infant learning occurs before parents realize that it is taking place. Further tests in my

SOURCE: PATRICIA K. KUHL

Graphic by Daisy Chung

lab, however, produced a significant new finding that lends an important caveat to this story: the statistical-learning process does not require passive listening alone.

BABY MEET AND GREET

IN OUR WORK, we discovered that infants need to be more than just computational geniuses processing clever neural algorithms. In 2003 we published the results of experiments in which nine-month-old infants from Seattle were exposed to Mandarin Chinese. We wanted to know whether infants' statistical-learning abilities would allow them to learn Mandarin phonemes.

In groups of two or three, the nine-month-olds listened to Mandarin native speakers while their teachers played on the floor with them, using books and toys. Two additional groups were also exposed to Mandarin. But one watched a video of Mandarin being spoken. Another listened to an audio recording. A fourth group, run as a control, heard no Mandarin at all but instead listened to U.S. graduate students speaking English while playing with the children with the same books and toys. All of this happened during 12 sessions that took place over the course of a month.

Infants from all four groups returned to the lab for psychological tests and brain monitoring to gauge their ability to single out Mandarin phonemes. Only the group exposed to Chinese from live speakers learned to pick up the foreign phonemes. Their performance, in fact, was equivalent to infants in Taipei who had been listening to their parents for their first 11 months.

Infants who were exposed to Mandarin by television or audio did not learn at all. Their ability to discriminate phonemes matched infants in the control group, who, as expected, performed no better than before the experiment.

The study provided evidence that learning for the infant brain is not a passive process. It requires human interaction—a necessity that I call "social gating." This hypothesis can even be extended to explain the way many species learn to communicate. The experience of a young child learning to talk, in fact, resembles the way birds learn song.

Learning for the infant brain is not a passive process. Social interaction is an essential prerequisite for mastering a language.

I worked earlier with the late Allison Doupe of the University of California, San Francisco, to compare baby and bird learning. We found that for both children and zebra finches, social experience in the early months of life was essential. Both human and bird babies immerse themselves in listening to their elders, and they store memories of the sounds they hear. These recollections condition the brain's motor areas to produce sounds that match those heard frequently in the larger social community in which they were being raised.

Exactly how social context contributes to the learning of a language in humans is still an open question. I have suggested, though, that parents and other adults provide both motivation and necessary information to help babies learn. The motivational component is driven by the brain's reward systems—and, in particular, brain areas that use the neurotransmitter dopamine during social interaction. Work in my lab has already shown that babies learn better in the presence of other babies—we are

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currently engaged in studies that explain why this is the case.

Babies who gaze into their parents' eyes also receive key social cues that help to speed the next stage of language learning—the understanding of the meaning of actual words. Andrew Meltzoff of the University of Washington has shown that young children who follow the direction of an adult's gaze pick up more vocabulary in the first two years of life than children who do not track these eye movements. The connection between looking and talking makes perfect sense and provides some explanation of why simply watching an instructional video is not good enough.

In the group that received live lessons, infants could see when the Mandarin teacher glanced at an object while naming it, a subtle action that tied together the word with the object named. In a paper published in July, we also showed that as a Spanish tutor holds up new toys and talks about them, infants who look back and forth between the tutor and the toy, instead of just focusing on one or the other, learn the phonemes as well as words used during the study session. This example is an illustration of my theory that infants' social skills enable—or "gate"—language learning.

These ideas about the social component of early language learning may also explain some of the difficulties encountered by infants who go on to develop disorders such as autism. Children with autism lack basic interest in speaking. Instead they fixate on inanimate objects and fail to pay attention to social cues so essential in language learning.

SAY, "HIIIII!"

AN INFANT'S ABILITY to learn to speak depends not only on being able to listen to adults but also on the manner in which grown-ups talk to the child. Whether in Dhaka, Paris, Riga or the Tulalip Indian Reservation near Seattle, researchers who listen to people talk to a child have learned one simple truth: an adult speaks to a child differently than to other adults. Cultural ethnographers and linguists have dubbed it "baby talk," and it turns up in most cultures. At first, it was unknown whether baby talk might hinder language learning. Numerous studies, however, have shown that motherese or parentese, the revisionist name for baby talk, actually helps an infant learn. Parentese, in fact, is not a modern invention: Varro (116 to 27 B.C.), an ancient Roman expert on syntax, noted that certain shortened words were used only when talking to babies and young children.

My lab—and those of Anne Fernald at Stanford University and Lila Gleitman at the University of Pennsylvania—has looked at the specific sounds of parentese that intrigue infants: the higher pitch, slower tempo and exaggerated intonation. When given a choice, infants will choose to listen to short audio clips of parentese instead of recordings of the same mothers speaking to other adults. The high-pitched tone seems to act as an acoustic hook for infants that captures and holds their attention.

Parentese exaggerates differences between sounds—one phoneme can be easily discriminated from another. Our studies show that exaggerated speech most likely helps infants as they commit these sounds to memory. In a recent study by my group, Nairán Ramírez-Esparza, now at the University of Connecticut, had infants wear high-fidelity miniature tape recorders fitted into lightweight vests worn at home throughout the day. The recordings let us enter the children's auditory world and showed that if their parents spoke to them in parentese at that age, then one year later these infants had learned more than twice the number of words as those whose parents did not use the baby vernacular as frequently.

SIGNATURES OF LEARNING

BRAIN SCIENTISTS WHO STUDY child development are becoming excited about the possibility of using our growing knowledge of early development to identify signatures of brain activity, known as biomarkers, that provide clues that a child may be running into difficulty in learning language. In a recent study in my lab, two-year-old children with autism spectrum disorder listened to both known and unfamiliar words while we monitored their brain's electrical activity when they heard these words.

We found the degree to which a particular pattern of brain waves was present in response to known words predicted the child's future language and cognitive abilities, at ages four and six. These measurements assessed the child's success at learning from other people. They show that if a youngster has the ability to learn words socially, it bodes well for learning in general.

The prospect for being able to measure an infant or toddler's cognitive development is improving because of the availability of new tools to judge their ability to detect sounds. My research group has begun to use magnetoencephalography (MEG), a safe and noninvasive imaging technology, to demonstrate how the brain responds to speech. The machine contains 306 SQUID (superconducting quantum interference device) sensors placed within an apparatus that looks like a hair dryer. When the infant sits in it, the sensors measure tiny magnetic fields that indicate specific neurons firing in the baby's brain as the child listens to speech. We have already demonstrated with MEG that there is a critical time window in which babies seem to be going through mental rehearsals to prepare to speak their native language.

MEG is too expensive and difficult to use in a neighborhood medical clinic. But these studies pave the way by identifying biomarkers that will eventually be measured with portable and inexpensive sensors that can be used outside a university lab.

If reliable biomarkers for language learning can be identified, they should help determine whether children are developing normally or at risk for early-life, language-related disabilities, including autism spectrum disorder, dyslexia, fragile X syndrome and other disorders. By understanding the brain's uniquely human capacity for language—and when exactly it is possible to shape it—we may be able to administer therapies early enough to change the future course of a child's life. SA

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Our sense of the universe as an orderly expanse where events happen in absolute locations is an illusion

By George Musser

PHYSICS

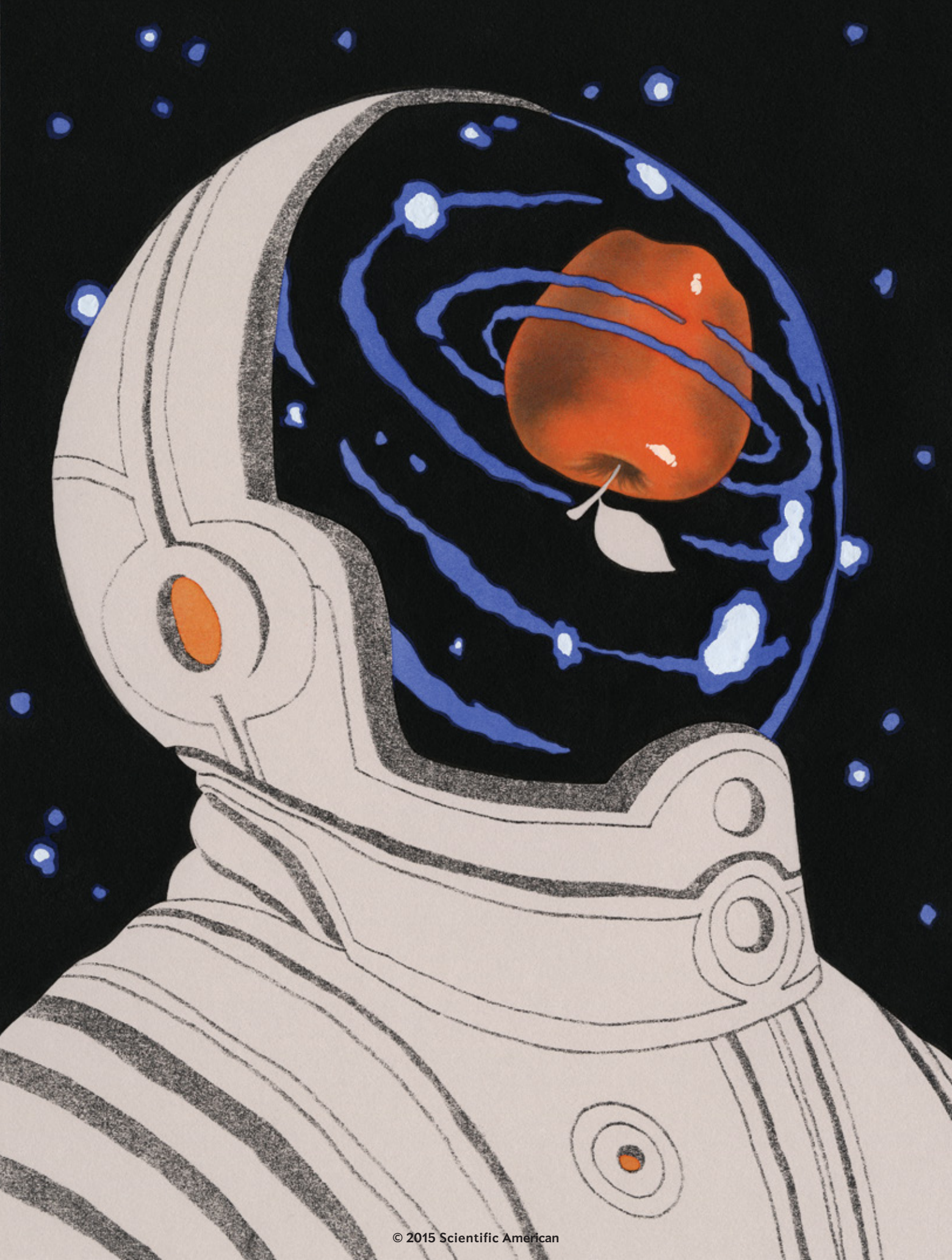
Where Is Here?

WHEN I FIRST LEARNED ABOUT THE QUANTUM PHENOMENON KNOWN AS NONLOCALITY in the early 1990s, I was a graduate student. But I didn't hear about it from my quantum-mechanics professor: he didn't see fit to so much as mention it. Browsing in a local bookshop, I picked up a newly published work, *The Conscious Universe,* which startled me with its claim that "no previous discovery has posed more challenges to our sense of everyday reality" than nonlocality. The phenomenon had the taste of forbidden fruit.

In everyday speech, "locality" is a slightly pretentious word for a neighborhood, town or other place. But its original meaning, dating to the 17th century, is about the very concept of "place." It means that everything *has* a place. You can always point to an object and say, "Here it is." If you can't, that thing must not really exist. If your teacher asks where your homework is, and you say it isn't anywhere, you have some explaining to do.

The world we experience possesses all the qualities of locality. We have a strong sense of place and of the relations among places. We feel the pain of separation from those we love and the impotence of being too far away from something we want to affect. And yet multiple branches of physics now suggest that, at a deeper level, there may be no such thing as place and no such thing as distance. Physics experiments can bind the fate of two particles together so that they behave like a pair of magic coins. If you flip them, each will land on heads or tails—but always on the same side as its partner. They act in a coordinated way even though no force passes through

Illustration by Edward Kinsella III



the space between them. Those particles might zip off to opposite sides of the universe, and still they act in unison. The particles violate locality—they transcend space.

Evidently nature has struck a peculiar and delicate balance: under most circumstances it obeys locality, and it *must* obey locality if we are to exist, yet it drops hints of being nonlocal at its foundations. For those who study it, nonlocality is the mother of all physics riddles, implicated in a broad cross section of the mysteries that physicists confront these days—not just the weirdness of quantum particles but also the fate of black holes, the origin of the cosmos and the essential unity of nature.

For most of the 20th century, quantum entanglement—the peculiar synchronicity of particles—was the only type of nonlocality that rated any mention. It was the phenomenon that Albert Einstein called "spooky action at a distance." But physicists gradually realized that other phenomena are suspiciously spooky, too.

For instance, Einstein created his general theory of relativity—which provides our modern understanding of gravity—with the express purpose of expunging nonlocality from physics. Isaac Newton's gravity acted at a distance, as if by magic, and general relativity snapped the wand in two by showing that the curvature of spacetime, and not an invisible force, gives rise to gravitational attraction. But whatever Einstein's intention may have been, his theory began to reveal a different side as physicists put it to use. The workings of gravity turn out to be sparkling with nonlocal phenomena.

WHAT WE MEAN BY "HERE"

ONE DAY IN AUTUMN, Don Marolf, a physicist at the University of California, Santa Barbara, and I were talking about gravity while sitting in the student center of his campus, eating salads and looking out over the lagoon. But hang on. How did I really know I was sitting in the U.C.S.B. student center on a certain day in autumn? The principle of locality says that I had a position, the student center had a position, and when these two positions coincided, I was there. The GPS coordinates on my phone matched those of the center, and the date matched the calendar on the wall. But this seemingly straightforward procedure doesn't stand up on examination. "To ask a question about here, we should know what we mean by 'here,' and that's not so easy to do," Marolf says.

One obvious complication is that California is tectonically active. The crustal plate on which Santa Barbara sits is moving northwest by a couple of inches per year relative to the rest of North America and to the national latitude and longitude grid. So the student center has no fixed position. If I come back some years from now and go to the same coordinates, I'll find myself sitting in that lagoon. Mapping companies must periodically resurvey tectonic zones to account for this motion.

You might suppose that the student center still has a position defined in an absolute sense by space itself. Yet space and time are no more stable than a tectonic plate. They can slide, heave and buckle. When a massive body shifts, it sends tremors through the spacetime continuum, resculpting it. The position of the cafeteria might change as a result, even if the tectonic plate stays put. This process, rather than Newton's mysterious action at a distance, is how gravity is communicated from one place to another, according to Einstein's general theory of relativity. Like geologic tremors, gravitational ripples propagate at a certain finite speed—namely that of light.

To grasp the reshaping of spacetime, our minds have to overcome a hurdle of abstraction. Spacetime is not as tangible as a geologic landscape. We can't see it, let alone discern its shape. Yet we catch indirect glimpses. Objects that are moving freely through space, unhindered by other objects, are like raindrops streaking across a car windshield, revealing the curve of the glass: they trace out the shape of space. For instance, astronomers routinely observe rays of starlight that begin as parallel, pass near a giant lump of mass such as the sun, then afterward intersect. Textbooks and articles describing this effect often say that the sun's gravity has bent the light rays, but that's not quite right. The rays are as straight as straight can be. What the sun has really done is to alter the rules of geometry—that is, to warp space—such that parallel lines can meet.

The morphing of space and time is not just the stuff of exotic physics. It governs the motion of any falling object. Baseballs, wineglasses, expensive smartphones: things that slip out of your hand accelerate toward the floor because Earth's mass warps time. (The warping of space plays only a minor role in these cases.) "Down" is defined by the direction in which time passes more slowly. Clocks at sea level tick more slowly than clocks on the summit of Denali; a watch strapped to your ankle will fall behind one on your wrist. In human terms, the deviations are small—parts in a trillion at most—but enough to account for the rate at which falling objects pick up speed. When you see an apple fall from a tree, you are watching it roll across the contours of time.

RELATIVITY'S REVELATION

ALTHOUGH THE SHAPE SHIFTINESS of spacetime explains away the kind of nonlocality that Newton talked about, it produces a new variety. It comes out of relativity theory's core innovation: that

George Musser is a contributing editor at *Scientific American* and author of *The Complete Idiot's Guide to String Theory* (Alpha Books, 2008).

IN BRIEF

In everyday life, distance and location are mundane absolutes. Yet physics now suggests that at the most fundamental level, the universe is nonlocal—there is no such thing as place or distance.

Initially Isaac Newton's conception of gravity seemed to imply the phenomenon of nonlocality because the attractive force between masses appeared to act magically across expanses.

Albert Einstein's general relativity instead ascribed gravity to the curvature of spacetime. Yet it introduced a deeper sense of nonlocality by showing that spacetime positions have no intrinsic meaning.

SCIENTIFIC AMERICAN ONLINE Watch a video primer on general relativity at ScientificAmerican.com/nov2015/musser

there's no such thing as a place outside spacetime, no external or absolute standard to judge it by. This seemingly self-evident proposition has remarkable consequences. It means that spacetime not only warps but also loses many of the qualities we associate with it, including the ability to define locations.

Disavowing a god's-eye perspective, Marolf says, "is very subtle, and, honestly, Einstein didn't understand it for a long time." Previous conceptions of space, including Newton's and even Einstein's own earlier thinking, supposed that space had a fixed geometry, which would let you imagine rising above space and looking down on it. In fact, at one point, Einstein argued there *had* to be an absolute reference point or else the shape of space would become ambiguous.

For a sense of why the ambiguity arises, consider how we experience geography in everyday life. We might suppose there is a unique "real" shape to the landscape—what Google Earth shows—but in practice the shape is defined by the experience of being embedded within that landscape, and that experience can vary. A student running late to an exam, an athlete hobbling on a sprained ankle, a professor walking with a colleague while deep in conversation and a cyclist yelling at pedestrians to get out of the way will perceive very different campuses. A short distance for one may seem an interminable crossing to another. When we eschew the view from on high, we can no longer make definitive statements about what is where.

In an epiphany in 1915, Einstein realized that the ambiguity is not a bug but a feature. He noted that we never observe places to have absolute locations, anyway. Instead we assign positions based on how objects are arranged relative to one another, and—crucially—those relative locations are objective. Everyone wandering around the college campus will recognize the basic ordering of places. They will juxtapose the U.C. student center with the lagoon rather than putting them on opposite sides of campus. If the landscape buckled or flowed while preserving these relations, the denizens would never know. So it is for spacetime. Different observers may ascribe different locations to a place but will agree on the relations that places bear to one another. These relations are what determine the events that occur. "If George and Don met in a certain café at noon in the first spacetime," Marolf tells me, "they would also do so in the reshuffled spacetime. It's just that in the first case this would have occurred at point B, and in the reshuffled case it occurs at point A."

The cafeteria, then, is situated at A or B or C or D or E—an infinity of possible positions. When we say it's located at such and such a place, we're really using a shorthand for its relations to other landmarks. Lacking definitive coordinates, the cafeteria must be situated by the things within and around it. To locate it, you'd need to search the world over for a place where the tables, chairs and salad bar are arranged just so and where a patio overlooks a lagoon bathed in the golden sunlight of southern California. The position of the student center is a property not of the center but of the entire system to which it belongs. "The question you asked in principle refers to the whole spacetime," Marolf says.

The ambiguity of localized measurements is a form of nonlocality. To begin with, quantities such as energy can't be situated in any specific place, for the simple reason that there is no such thing as a specific place. You can no sooner pin down a position than you can plant a flag on the sea. Points in space are indistinguishable and interchangeable. Because they lack any differentiating attributes, whatever the world consists of must not reside at points; space is unable to support any localized structure. Gravitational quantities must instead be holistic—properties of spacetime in its entirety.

Furthermore, the multiple equivalent shapes of space are described by different configurations of the gravitational field. In one configuration, the field might exert a stronger force in one place than it would in another configuration, with compensating changes elsewhere to maintain the relative arrangement of objects. Points in the gravitational field must be interlinked with one another so that they can flop around while collectively still producing the same internal arrangement of objects. These linkages violate the principle that individual locations in space have an autonomous existence. Marolf has put it this way: "Any theory of gravity is not a local field theory. Even classically there are important constraint equations. The field at *this* point in spacetime and the field at *this* point in spacetime are not independent."

Under most circumstances, we can ignore this nonlocality. You can designate some available chunk of matter as a reference point and use it to anchor a coordinate grid. You can, to the chagrin of Santa Barbarans, take Los Angeles as the center of the universe and define every other place with respect to it. In this framework, you can go about your business in blissful ignorance of space's fundamental inability to demarcate locations. "Once you've done that, the physics looks like it's local," Marolf says. "The dynamics of gravity is completely local. Things move in a continuous way, limited by the speed of light." But the properties of gravity are still only "pseudo local." The nonlocality is always there, lurking beneath the surface, emerging under extreme circumstances such as black holes.

In short, Einstein's theory is nonlocal in a more subtle and insidious way than Newton's theory of gravity was. Newtonian gravity acted at a distance, but at least it operated within a framework of absolute space. Einsteinian gravity has no such element of wizardry; its effects ripple through the universe at the speed of light. Yet it demolishes the framework, violating locality in what was, for Einstein, its most basic sense: the stipulation that all things have a location. General relativity confounds our intuitive picture of space as a kind of container in which material objects reside and forces us to search for an entirely new conception of place. SA

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For videos, blog posts and explainers of nonlocality, visit www.georgemusser.com

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scientificamerican.com/magazine/sa

RECOMMENDED

By Clara Moskowitz

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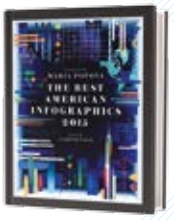
SCIENTIFICAMERICAN.COM/NOV2015/RECOMMENDED

The Best American Infographics 2015

edited by Gareth Cook. Mariner, 2015 ($20)

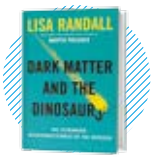


At their best, information graphics can bridge the practical and the poetic, writes journalist Maria Popova in the introduction to this collection. The displays curated by *Scientific American Mind* contributing editor Cook do just that, catapulting readers into a world of data designed to enthrall. (*Scientific American* editor in chief Mariette DiChristina and senior graphics editor Jen Christiansen were advisers for the book.) One graphic maps the voyaging path of Jean Harlow's beauty mark, rarely spotted in the same place twice. Another, more sobering page pairs rows of empty baby clothes with the ages of infants who died in Virginia day care centers. The diverse charts range in topic from trilobites and bioluminescent critters to blueprints of start-up costs and Ebola's entry into the immune system.

—Sabrina Imbler

Dark Matter and the Dinosaurs: The Astounding Interconnectedness of the Universe

by Lisa Randall. HarperCollins, 2015 ($29.99)



Exotic entities such as dark matter—the invisible material thought to make up about 27 percent of the universe—do not seem to have any direct impact on our lives here on Earth. But physicist Randall pokes a hole in that notion by proposing that a rogue disk of weird dark matter might have been responsible for aiming the comet that scientists suspect hit Earth and killed our planet's dinosaurs 66 million years ago. To examine the plausibility of that scenario, Randall's book traverses many scientific fields, including chemistry, planetary science and cosmology. Guided by her theory about the dinosaurs' demise, the author explores the often unappreciated connections between the tiniest particles right under our noses and the vastest structures that rule the universe. (Randall serves on the magazine's board of advisers.) *—Maria Temming*

Suspicious Minds: Why We Believe Conspiracy Theories

by Rob Brotherton. Bloomsbury Sigma, 2015 ($19.99)

In this investigation of the psychology behind conspiracy theories, psychologist Brotherton explores how different people can reach wildly divergent conclusions about reality. He casts doubt on the assumption that far-fetched beliefs are reserved for the simple-minded or the exceedingly paranoid. "We are all natural-born conspiracy theorists," Brotherton writes. He delves into the nature of belief to illustrate the ways that our susceptibility to tall tales is related to other natural tendencies, such as our inclination to arrange random data points into a seemingly meaningful pattern and our propensity to ascribe intentions behind sometimes random events. Although we like to think our judgments are based on evidence, Brotherton reveals that a host of psychological factors come into play whenever we choose what to believe. *—M.T.*

Black Man in a White Coat: A Doctor's Reflections on Race and Medicine

by Damon Tweedy. Picador, 2015 ($26)

As a black doctor, author Tweedy has first-hand knowledge of how, for complicated social, cultural and economic reasons, "being black can be bad for your health." For instance, African-Americans face an increased risk of problems such as diabetes, heart disease and stroke and an infant mortality rate twice that of whites. Tweedy experiences this sad truth from both sides of the stethoscope and relates his challenges in navigating the predominantly white medical world as a patient and a professional. He remembers, for example, his frustration at his own diagnosis of hypertension and his insecurity and anger the day his professor mistook him for a handyman. Yet Tweedy's unfailing empathy for both his patients and colleagues serves as a model for how increased understanding between doctors and those they serve can help forge a more equitable world. *—S.I.*

COURTESY OF *NATURE* (*illustration spread*)

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His new book is *The Moral Arc* (Henry Holt, 2015). Follow him on Twitter @michaelshermer

Perception Deception

Do we perceive reality as it is?

By Michael Shermer

One of the deepest problems in epistemology is how we know the nature of reality. Over the millennia philosophers have offered many theories, from solipsism (only one's mind is known to exist) to the theory that natural selection shaped our senses to give us an accurate, or verdical, model of the world. Now a new theory by University of California, Irvine, cognitive scientist Donald Hoffman is garnering attention. (Google his scholarly papers and TED talk with more than 1.4 million views.) Grounded in evolutionary psychology, it is called the interface theory of perception (ITP) and argues that percepts act as a species-specific user interface that directs behavior toward survival and reproduction, not truth.

Hoffman's computer analogy is that physical space is like the desktop and that objects in it are like desktop icons, which are produced by the graphical user interface (GUI). Our senses, he says, form a biological user interface—a gooey GUI—between our brain and the outside world, transducing physical stimuli such as photons of light into neural impulses processed by the visual cortex as things in the environment. GUIs are useful because you don't need to know what is inside computers and brains. You just need to know how to interact with the interface well enough to accomplish your task. Adaptive function, not veridical perception, is what is important.

Hoffman's holotype is the Australian jewel beetle *Julodimorpha bakewelli*. Females are large, shiny, brown and dimpled. So, too, are discarded beer bottles dubbed "stubbies," and males will mount them until they die by heat, starvation or ants. The species was on the brink of extinction because its senses and brain were designed by natural selection not to perceive reality (it's a beer bottle, you idiot!) but to mate with anything big, brown, shiny and dimply.

To test his theory, Hoffman ran thousands of evolutionary computer simulations in which digital organisms whose perceptual systems are tuned exclusively for truth are outcompeted by those tuned solely for fitness. Because natural selection depends only on expected fitness, evolution shaped our sensory systems toward fitter behavior, not truthful representation.

ITP is well worth serious consideration and testing, but I have my doubts. First, how could a more accurate perception of reality *not* be adaptive? Hoffman's answer is that evolution gave us an interface to hide the underlying reality because, for example, you don't need to know how neurons create images of snakes; you just need to jump out of the way of the snake icon. But how did the icon come to look like a snake in the first place? Natural selection. And why did some nonpoisonous snakes evolve to mimic poisonous species? Because predators avoid *real* poisonous snakes. Mimicry works only if there is an objective reality to mimic.

Hoffman has claimed that "a rock is an interface icon, not a constituent of objective reality." But a real rock chipped into an arrow point and thrown at a four-legged meal works even if you don't know physics and calculus. Is that not veridical perception with adaptive significance?

As for jewel beetles, stubbies are what ethologists call supernormal stimuli, which mimic objects that organisms evolved to respond to and elicit a stronger response in doing so, such as (for some people) silicone breast implants in women and testosterone-enhanced bodybuilding in men. Supernormal stimuli operate only because evolution designed us to respond to normal stimuli, which must be accurately portrayed by our senses to our brain to work.

Hoffman says that perception is species-specific and that we should take predators seriously but not literally. Yes, a dolphin's icon for "shark" no doubt looks different than a human's, but there really are sharks, and they really do have powerful tails on one end and a mouthful of teeth on the other end, and that is true no matter how your sensory system works.

Also, computer simulations are useful for modeling how evolution might have happened, but a real-world test of ITP would be to determine if most biological sensory interfaces create icons that resemble reality or distort it. I'm betting on reality. Data will tell.

Finally, why present this problem as an either-or choice between fitness and truth? Adaptations depend in large part on a relatively accurate model of reality. The fact that science progresses toward, say, eradicating diseases and landing spacecraft on Mars must mean that our perceptions of reality are growing ever closer to the truth, even if it is with a small "t." SA

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Illustration by Izhar Cohen

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 34 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

Tushi Kicks Butt

In which Tushi the chimp extends her species' known tool use to drone removal

By Steve Mirsky

***Washington Post* headline, September 4, 2015:** "Chimp That Attacked a Drone with a Stick Planned Ahead, Researchers Say"

Classified report, September 20, 2015: Venue: Secure location, the Netherlands; translation of interview with damaged drone aircraft, performed by unidentified security official:

Security Official: It's been five months. In your own words, describe what happened.

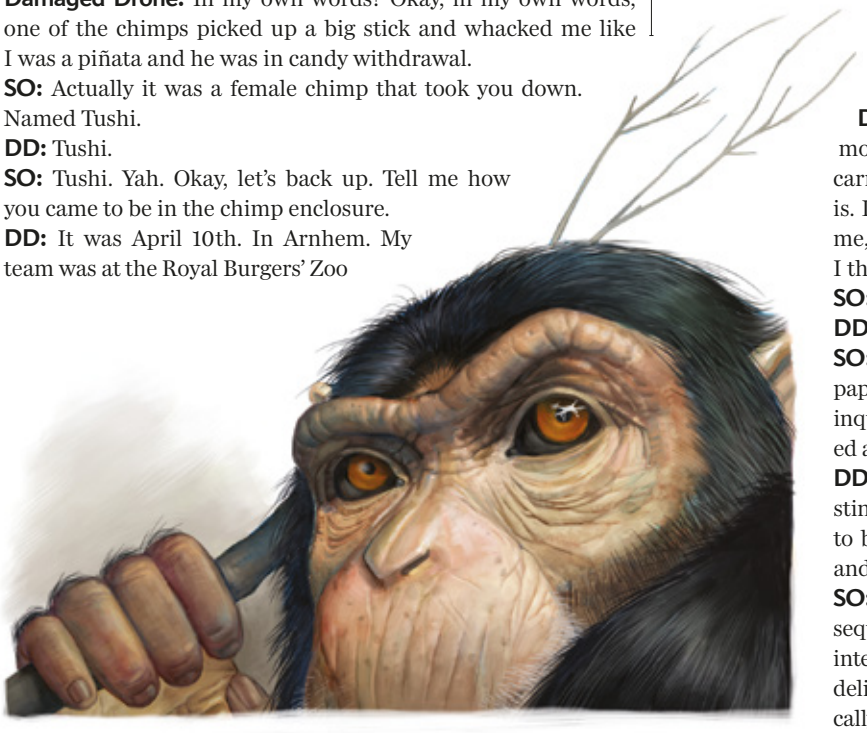
Damaged Drone: In my own words? Okay, in my own words, one of the chimps picked up a big stick and whacked me like I was a piñata and he was in candy withdrawal.

SO: Actually it was a female chimp that took you down. Named Tushi.

DD: Tushi.

SO: Tushi. Yah. Okay, let's back up. Tell me how you came to be in the chimp enclosure.

DD: It was April 10th. In Arnhem. My team was at the Royal Burgers' Zoo in Arnhem. We were supposed to shoot video of the chimps for the zoo. They're in a big enclosure. You could play the World Cup final in there. The producers wanted me to get overhead shots and from unusual angles, they said.



SO: Were you made aware that this chimp population has lived at the zoo since 1971 and is renowned for being the subject matter for studies of social behavior and tool use, including tool use "rarely if [ever] seen in the wild"?

DD: No, nobody told me that.

SO: Yes, that's according to a scientific paper about the incident, published online September 3rd by the journal *Primates*. Written by the famous primatologist Jan van Hooff, who's been studying this population since the 1970s, and Bas Lukkenaar, the zoo official who was supervising the shoot.

DD: Lukkenaar got a paper out of it?

SO: They titled it: "Captive Chimpanzee Takes Down a Drone: Tool Use toward a Flying Object." Anyway, so there you were—flying over.

DD: I made a trial run, no camera, and there were willow branches on the ground.

SO: Yes, the chimps get willow branches as treats. It's in the paper. They peel off the bark and eat the soft lining. Then the branches are there for them to play with.

DD: To play with. Yeah. Well, as I started flying, some of the chimps grabbed willow branches. To play with. And four chimps began climbing scaffolding on the side of the enclosure where I was hovering. I didn't think anything of it. Then I started a flight at 10 to 15 meters up, with the camera on. Chimps were quiet. Two of them were, oh, about five meters up on that scaffolding still.

SO: Tushi, born in that colony in 1992, and another female, Raimee, born there in 1999.

DD: Okay. So Tushi, it must have been, moves in my direction. In her left hand, she's carrying a willow branch about as long as she is. I got in closer. And she swings that thing at me, misses once and then smack. "I'm hit!" I thought, and then I augered in.

SO: You kept shooting.

DD: It was reflex. Hey, I'm a reflex camera.

SO: Let me read to you from the *Primates* paper: "The camera also caught some footage of inquisitive faces of chimpanzees as they inspected and moved this strange contraption."

DD: Yes! I remember thinking, "Take your stinking paws off me, you damn dirty ape," but to be honest, the paws weren't really stinking, and the ape wasn't particularly dirty.

SO: The scientific paper concludes that "the sequence of events is highly suggestive of an interpretation of the use of the stick as a planned, deliberate action to 'attack' the drone (agonistically motivated) or 'find out about' the drone (curiosity motivated)."

DD: All the same to me, pal.

SO: Lemme ask you. Amateurs, humans, are flying their drones near airports. You think patrol chimps could help protect commercial aviation?

DD: Go watch *King Kong* and tell me what you think. Forget typewriters and *Hamlet*. Give chimps an infinite number of willow branches and high enough scaffolding, and eventually you'll have the world's safest airport. SA

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Illustration by Matt Collins

King Solomon's Secret Treasure: FOUND

Ancient beauty trapped in mines for centuries is finally released and available to the public!

King Solomon was one of the wealthiest rulers of the ancient world. His vast empire included hoards of gold, priceless gemstones and rare works of art. For centuries, fortune hunters and historians dedicated their lives to the search for his fabled mines and lost treasure. But as it turns out, those mines hid a prize more beautiful and exotic than any precious metal: chrysocolla.

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The Agenda Setters

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STEM Summit 3.0: The Future of Education

New York Academy of Sciences, New York City | August 4, 2015

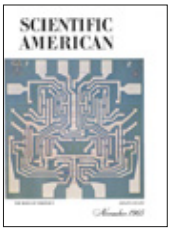
SCIENTIFIC AMERICAN and Macmillan Education joined forces to hold an extraordinary executive summit, which addressed building the 21st-century learner and inspiring the next generation to pursue STEM careers.

Editor in Chief **Mariette DiChristina**, an impressive lineup of speakers, including **Dr. Jo Handelsman**, White House Office of Science and Technology Policy, **Dr. Craig Barrett**, retired Chairman and CEO of Intel, **Jaime Casap**, Chief Education Evangelist at Google, **Joel Klein**, CEO of Amplify and Former Chancellor, New York City Department of Education, and many others.

50, 100 & 150 YEARS AGO

INNOVATION AND DISCOVERY AS CHRONICLED IN *SCIENTIFIC AMERICAN*

Compiled by Daniel C. Schlenoff



November 1965

Artificial Heart

"Up to a very few years ago the goal of planting an artificial heart in the body was not recognized as a bona fide scientific effort worthy of support, and papers describing experiments in that endeavor were not accepted by scientific or medical societies. Within the past five years, however, all of that has changed. Experimental animals (dogs and calves) have been kept alive for many hours with an artificial pump substituted for the natural heart in the chest. Artificial hearts in various versions are now available to investigators in a number of laboratories. The National Heart Institute is supporting the work by giving contracts to industry for development of these devices."

Gerrymandering

"In *Baker v. Carr,* its historic decision of March, 1962, the U.S. Supreme Court implied that the Constitution precludes inequality of population between state legislative districts. The Court has partially spelled out its view of what 'population equality' is required: the apportionment of seats and districting in the state must be so arranged that the number of inhabitants per legislator in one district is substantially equal to the number of inhabitants per legislator in any other district in the same state. The arrangements for legislative representation in many states were soon demonstrated to be a wonderland of alleged inequities. The prize went to the state of Vermont, where it was found that the most populous district had 987 times more people than the least populous district."

November 1915

Electric Railways

"Representing the last word in the electrification of steam railroad lines, the Chicago, Milwaukee & St. Paul Railway is electrifying 440 miles of its transcontinental system in connection with its through service between Chicago, Milwaukee, St. Paul, Minneapolis and the Pacific north coast. The current for operating the locomotives on the opening stretch of the electrified railroad is derived from Montana water power."

For a look at how electricity was improving life and technology in 1915, see www.ScientificAmerican.com/nov2015/electricity

Detecting Buried Shells

"When the erstwhile battlefields of Europe are reclaimed for the peaceful purposes of agriculture, there is an ever-present risk of death or serious injury to both the farmers and their horses as the result of plowshares coming in contact with buried shells that have failed to explode when fired. The instrument that has been devised by the French for the detection of buried shells is an adaptation of the Hughes induction balance. The original instrument was made by Professor C. Gutton at the request of the prefect of the Department of Meurthe-et-Moselle [in the Lorraine region], and with it the constructor was able to detect the presence of a small caliber shell at a depth of about 40 centimeters (nearly 16 inches)."

France and Belgium still clear hundreds of tons of unexploded ordnance a year from these century-old battlefields.

Induction balance helps to find unexploded shells in the former battlefields of France, **1915**

November 1865

Life in Other Solar Systems?

"Professor Miller and Mr. Huggins have constructed an instrument with which they have compared the spectra of the moon and planets and some of the fixed stars, and even of the nebulae with the spectra of the principal metals. It is observed by the authors of these valuable communications 'that the elements most widely diffused through the host of stars are some of them most closely connected with the constitution of the living organisms of our globe, including hydrogen, sodium, magnesium, and iron.' On the whole, we believe that the foregoing spectrum observations on the stars contribute something toward an experimental basis on which a conclusion, hitherto but a pure speculation, may rest, viz.: that at least the brighter stars are, like our sun, upholding and energizing centers of systems of worlds adapted to be the abode of living beings."

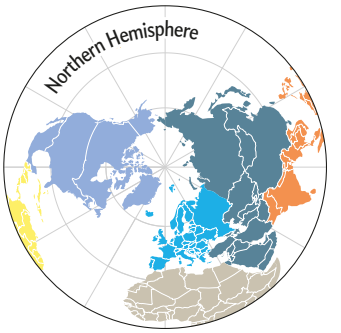
SCIENTIFIC AMERICAN, VOL. CXIII, NO. 20, NOVEMBER 13, 1915

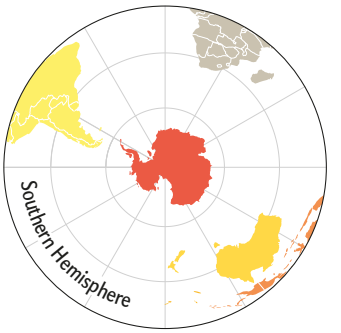
SCIENTIFIC AMERICAN ONLINE
TO SEE HOW PLANTS HAVE SHAPED EARTH'S SURFACE, GO TO SCIENTIFICAMERICAN.COM/NOV2015/GRAPHIC-SCIENCE

A Southward Invasion

Intrusive plants tend to originate in the Northern Hemisphere

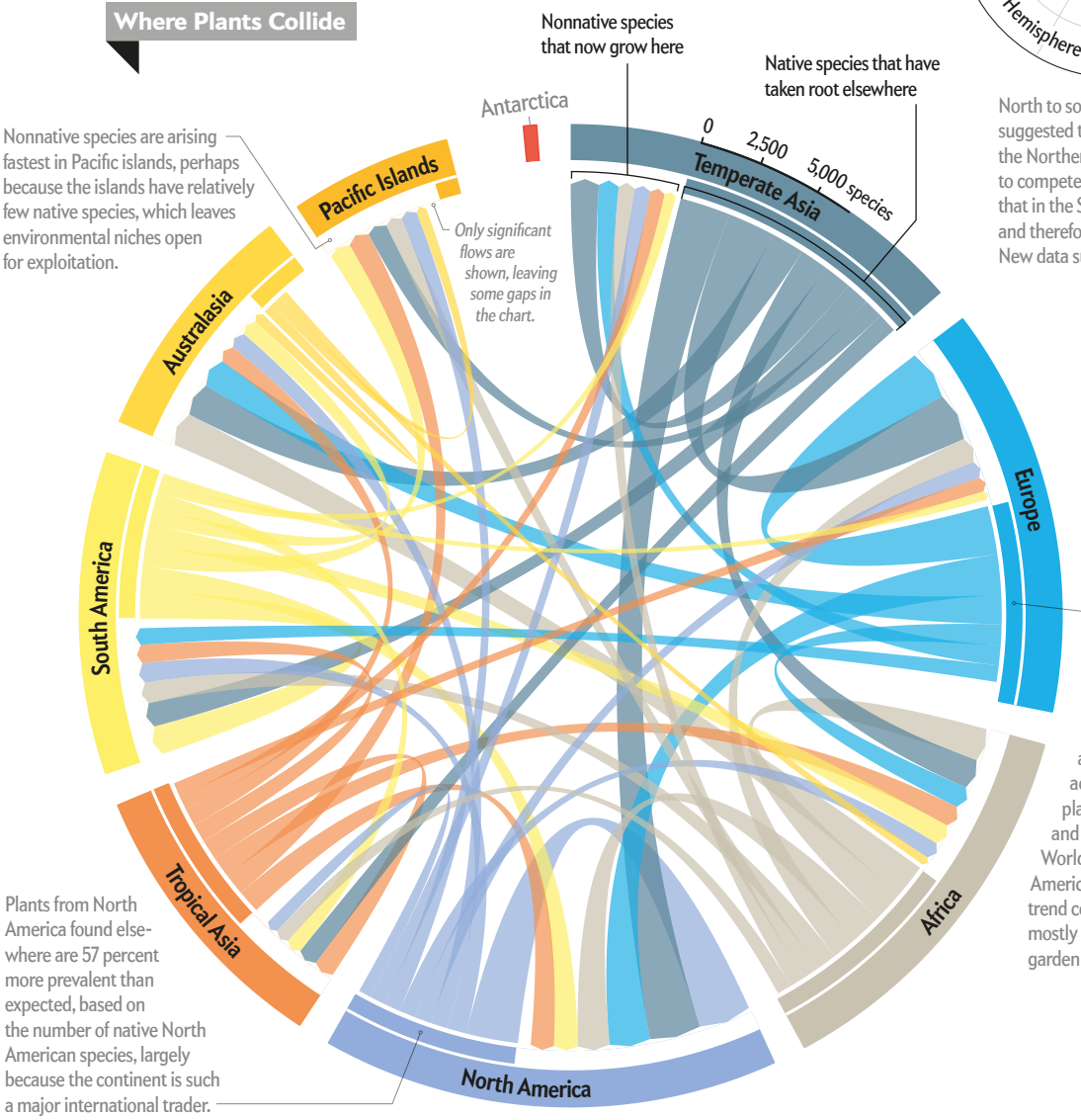
South America and tropical Asia have the most diverse plant life on earth, so it seems intuitive that these regions would supply much of the world's invasive species. But that's not the case, according to a new analysis of global plant databases led by Mark van Kleunen of the University of Konstanz in Germany. The data show more nonnative plants originating from temperate Asia and Europe than anywhere else. The numbers also indicate that more species move from the Northern Hemisphere south than vice versa, in part because of international trade patterns. Moreover, "it is very likely that the rate of invasion is increasing," van Kleunen says, because expansion of that trade, as well as general travel, "makes it easier for species to move between continents." —*Mark Fischetti*





North to south: Charles Darwin suggested that vegetation in the Northern Hemisphere had to compete harder to survive than that in the Southern Hemisphere and therefore should prevail. New data support that view.

Where Plants Collide



Nonnative species are arising fastest in Pacific islands, perhaps because the islands have relatively few native species, which leaves environmental niches open for exploitation.

Only significant flows are shown, leaving some gaps in the chart.

Plants from North America found elsewhere are 57 percent more prevalent than expected, based on the number of native North American species, largely because the continent is such a major international trader.

For centuries European traders, at times deliberately and at other times accidentally, brought plants to colonial Africa and Asia and to the New World of North and South America and Australia. The trend continues today, mostly for ornamental garden plants.

SOURCE: "GLOBAL EXCHANGE AND ACCUMULATION OF NON-NATIVE PLANTS," BY MARK VAN KLEUNEN ET AL., IN *NATURE*, VOL. 535; SEPTEMBER 3, 2015

Graphic by Mark van Kleunen, Maps by Terra Carta

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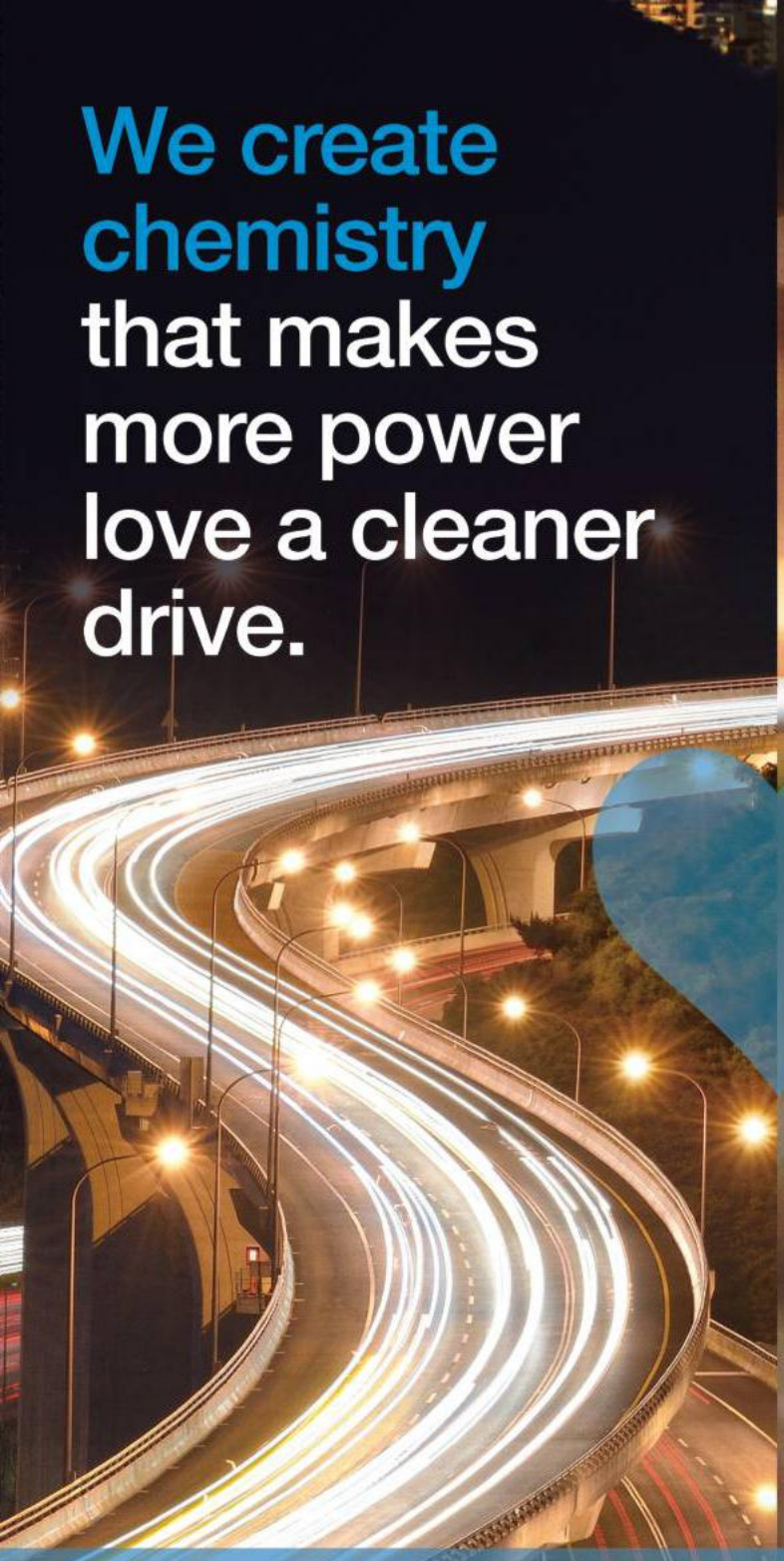

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