ASTRONOMY
Bizarre Worlds with Two Suns

AIR SECURITY
Dangers from Hacked Drones

CLIMATE CHANGE
New Solution: Use Methane?

SCIENTIFIC AMERICAN

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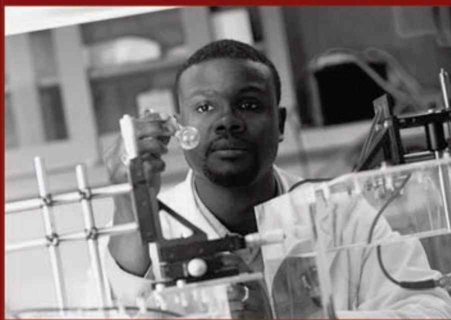
NOVEMBER 2013

King of Beasts

How our weak, defenseless ancestors became Earth's dominant predator

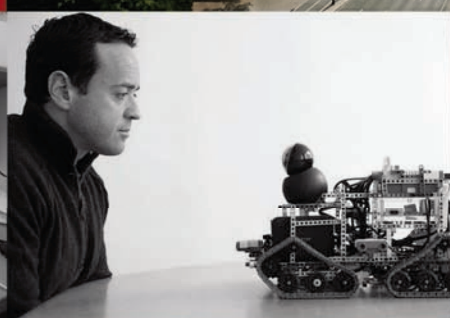
WHAT IS PRIVACY IN THE AGE OF BIG DATA?
By Jaron Lanier



CITIES ARE WARMER AND MORE PLEASANT.

TREES GROW FASTER AND LEAF EARLIER.

AND THAT'S JUST THE BEGINNING OF THE BAD NEWS.

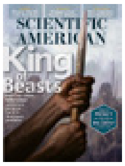




To get a real sense of how global warming is affecting our planet, we just need to look at what's happening on a much smaller scale in the cities where we live. Cities have a metabolism of their own, consuming energy in the form of fuel and resources, and producing waste — including carbon dioxide. Our researchers have followed the flow of carbon dioxide through urban areas — and have uncovered alarming facts about its impact on climate and vegetation. And while 70 percent of the world's carbon dioxide emissions come from cities, Boston University is one of the few leading research institutions to actively study urban ecosystems. Another example of how thinking differently about our world begins with BU. Find out more at **bu.edu/discover/cities**

The world needs to know.

BOSTON UNIVERSITY

ON THE COVER

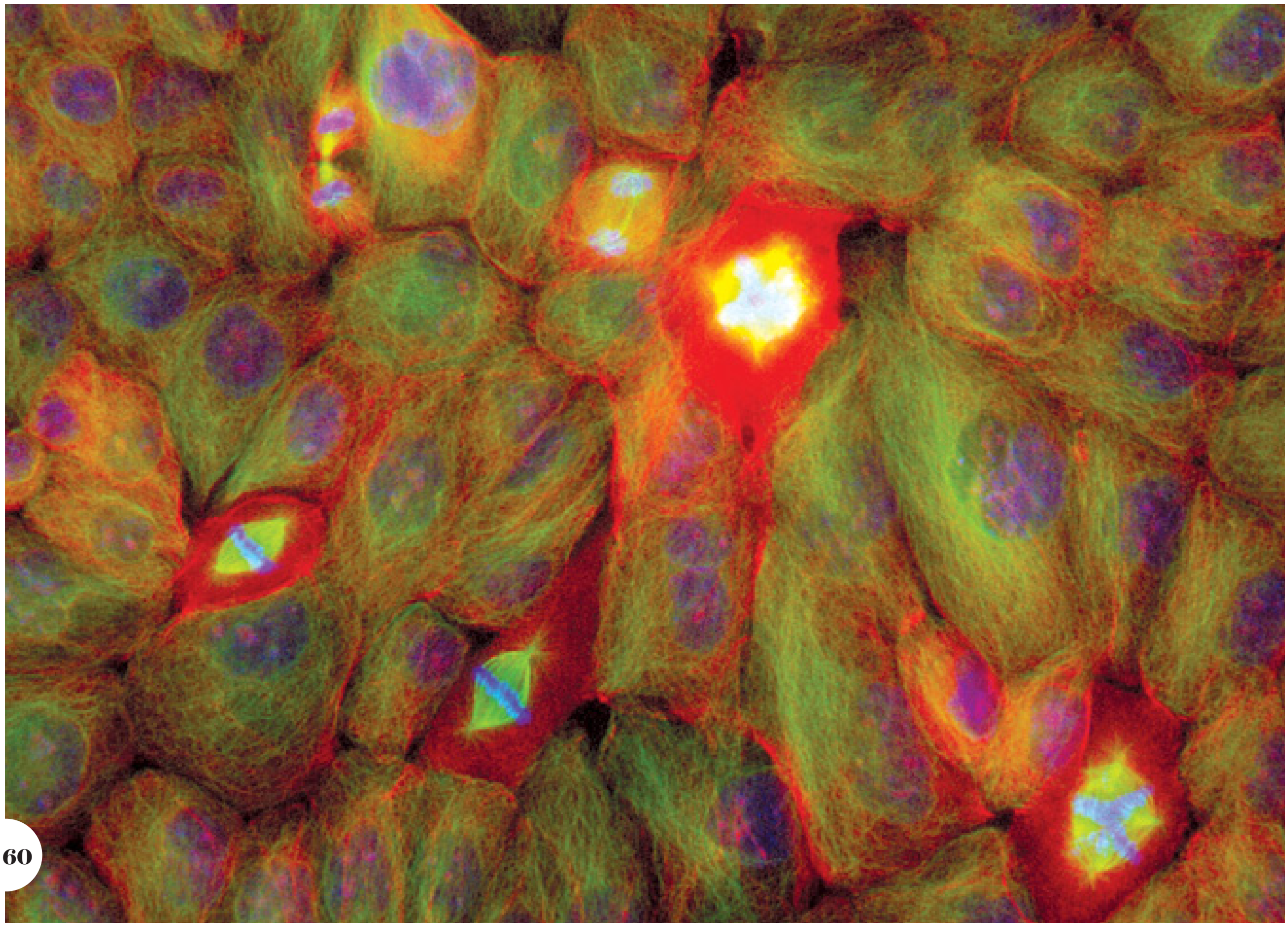


Early members of our genus, *Homo*, began driving Africa's sabertooth cats and other large carnivores to extinction more than two million years ago by competing with them for access to prey. The loss of these species would have precipitated dramatic ecological changes.

Illustration by David Palumbo.

SCIENTIFIC AMERICAN

November 2013, Volume 309, Number 5



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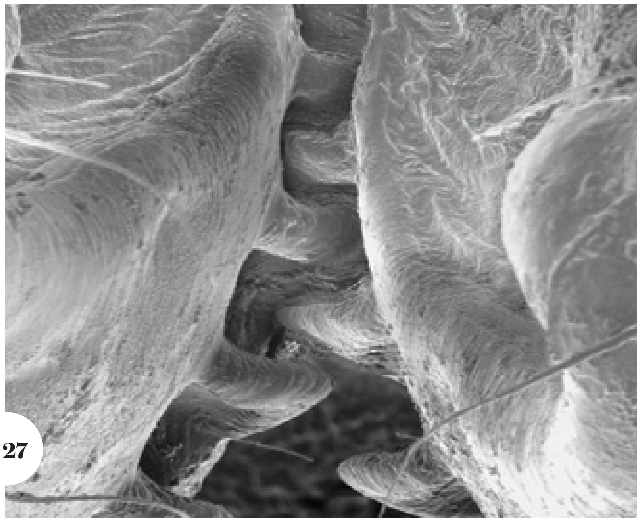
JENNIFER C WATERS *Science Source*

FEATURES



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DEPARTMENTS

ON THE WEB

Nobel Men and Women
Read about the scientists newly honored with this year's Nobel Prizes and delve into *Scientific American*'s archives for selections from articles authored by past Nobelists.
Go to www.ScientificAmerican.com/nov2013/nobel

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FOOTPRINTS—about 3.6 million years old—diverge at the Laetoli site in Tanzania.

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

Following Data Trails

Sometime around two million years ago the number and types of large carnivore species in Africa began to drop. Were our forebears responsible? In our cover story, "King of Beasts," paleontologist Lars Werdelin takes us down the data trail in search of an answer. Although our ancestors were slow and weak, he posits, they also proved to be clever and collaborative and, as omnivores, able to take advantage of opportunities for obtaining nourishing calories from a variety of different sources better than more dedicated meat eaters could. As a result, when times were the worst, they might have had a competitive advantage. Turn to page 34 to learn more.

Millennia later, with humans now firmly in the position of being the dominant species on our blue planet, we are taking the next step in understanding and managing our world through big data. Computers gather and analyze countless bits of our personal information. We leave a trail of our digital DNA with every click: what we buy online, the number and types of searches we make, and even where we go and when with our smartphones. Through the use of powerful algorithms that sift through the masses of recorded activities, we are making the world a more efficient, healthier and better-managed place to be sure. But, asks digital visionary Jaron Lanier, at what cost?

As Lanier explores in "How Should We Think about Privacy?" starting on page 64, privacy is more than an expectation of remaining at least a little mysterious to others. It is a lens through which we can explore our fast-changing notions surrounding its relation to power, politics and the law. Technology, he reminds us, is ultimately society's to wield as we collectively see fit.

"We still have the potential to choose what we want," Lanier writes. "It is as if we have forgotten the most basic fact about computers: they are programmable." SA

JOHN READER *Science Source*

Illustration by Nick Higgins

editors@sciam.com

July 2013

"The innovation and cooperation among nations required to stop climate change will happen only when the powerful realize they breathe the same air as the weak and the poor."

TOM FAULKNER *VIA E-MAIL*

CT SCANS AND CANCER

In "Do CT Scans Cause Cancer?" Carina Storrs accurately discusses the reasons diagnostic imaging with computed tomography scans has increased and the limited scientific knowledge of the effects of this increased radiation exposure on inducing cancer in patients. As a radiologist, I find that Storrs neglects to include one cause for the increase in CT scans: the current structure for how these exams are ordered in the U.S. health care system.

In the U.S., practicing physicians order diagnostic studies that they believe are appropriate. Radiologists, who are the experts in the advantages and disadvantages of different imaging modalities and are the ones that interpret the studies, have no ability to either reject or change the requested study without permission from the ordering physician. Consequently, a certain amount of nonoptimal and unneeded exams will be ordered.

This generally occurs because of lack of communication with the ordering physician to optimize the diagnostic test (the American Board of Radiology has developed appropriateness criteria for diagnostic studies to address this issue). Sadly, it also occurs because in the current U.S. reimbursement structure, there is no financial incentive to cancel a nonindicated or nonoptimized study.

Benjamin L. Viglianti
Department of Radiology
University of Michigan

CLIMATE TIPPING POINT

In "Greenhouse Goo," David Biello reports on efforts to halt the Keystone XL pipeline. By allowing for increased heavy oil production in the Alberta tar sands, the pipeline would accelerate the buildup to the cumulative carbon-emissions threshold of one trillion metric tons, at which we will reach the feared "tipping point" of more than two degrees Celsius of warming. The article points out that emissions must drop by 2.5 percent a year, starting now, for us not to exceed that threshold by 2041. Such an annual reduction would mean cutting energy use from carbon in half in about 30 years. One possible way to get there is by cutting world economic output in half. No one will willingly do that. At least not until economic collapse occurs following runaway atmospheric heating.

Incredible innovation and cooperation among nations are required. That will happen only when the majority of the powerful people of the wealthy nations realize they breathe the same air as the weak and the poor. The history of human behavior makes that outcome seem most unlikely.

Tom Faulkner
via e-mail

For 40 years I have watched environmentalists block hydroelectric power, nuclear power, offshore oil drilling, continental gas drilling and wind power projects. This focus on "purity of purpose" rather than "consequences of actions" resulted in utilities building dozens of heavily polluting coal plants and oil companies investing billions of dollars in Canadian tar sands.

The recent breakthroughs in fracking have reduced carbon emissions as utilities have begun to switch from coal to now dramatically cheaper natural gas. The potential use of natural gas in vehicles will reduce emissions even more. Unfortunately, since fracking doesn't meet the zealots' agenda, these significant environmental benefits are being strongly opposed.

Robert Gallant
Midland, Mich.

There is one major omission with regard to alternatives if Keystone fails: the energy-transport company Enbridge. While all attention has been on Keystone, Enbridge has been quietly building its own tar sands network to the Gulf and East coasts.

"jinsko"
commenting at
www.ScientificAmerican.com

SEEING IS FEELING

In "Once Blind and Now They See," Pawan Sinha describes his work in surgically curing cataract-caused blindness in children in India.

Sinha's comments on "intermodal organization"—in which information received through the eyes is correlated with that received through the other senses—reminded me of Annie Dillard recounting the story of the first successful cataract operations in Europe in her 1974 nonfiction narrative *Pilgrim at Tinker Creek*. Quoting an English translation of the 1932 book *Space and Sight,* she wrote: "Before the operation a doctor would give a blind patient a cube and a sphere; the patient would tongue it or feel it with his hands, and name it correctly. After the operation the doctor would show the same objects to the patient without letting him touch them; now he had no clue whatsoever what he was seeing. One patient called lemonade 'square' because it pricked on his tongue as a square shape pricked on the touch of his hands."

Bill Peak
Easton, Md.

FELINE GRIEF

"When Animals Mourn," by Barbara King, discusses evidence of nonhuman mourning, including in cats.

Our cats, Simba and Nala, were littermates and for 14 years were never more

than a few feet from each other. Nineteen months ago Simba had to be put down.

Nala immediately began to have spells of howling every day. She goes from room to room, calling in each. The raw anguish in her tone is unmistakable.

If she perceives a threat, she claws frantically at the bed coverlet where Simba would burrow for his naps. I often lie in bed reading my current magazine, which I rest on my raised knees: the two of them would crawl under my knees and cuddle there. Nala now checks into that empty space, emits one of her anguished howls, leaves and glares accusingly at me.

It is dangerous to draw conclusions from anecdotes, but Nala richly meets the criteria for grief given in the article. She is, unmistakably, mourning for her brother.

Frank Gue
Burlington, Ontario

GUN GUIDELINES

"Family, Friends and Gunshot," by Mark Fischetti [Graphic Science], illustrates statistics that show that in the U.S., guns are used more than other weapons in killings and that people are most often killed with them by others whom they know.

I would like two things to address gun violence: 1) Better education required for gun owners on how to effectively store and operate their firearm and on when it is appropriate to use it. 2) Better requirements and solutions for the safe storage and possession of a firearm.

I'm not talking about a full ban but about making it a requirement that those who own a firearm have a full and working understanding of it and its consequences.

"huntershoptaw"
commenting at
www.ScientificAmerican.com

ERRATA

"Going Deep," by Larry Greenemeier [Advances], refers to James Cameron performing the first manned mission to the Pacific Ocean's Challenger Deep site in *DEEPSEA CHALLENGER*. It should have stated that his was the first solo manned mission.

In "Walls of Water," by Dana Mackenzie, George Haller's affiliation was outdated; he is at the Swiss Federal Institute of Technology Zurich.

LETTERS TO THE EDITOR

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/nov2013

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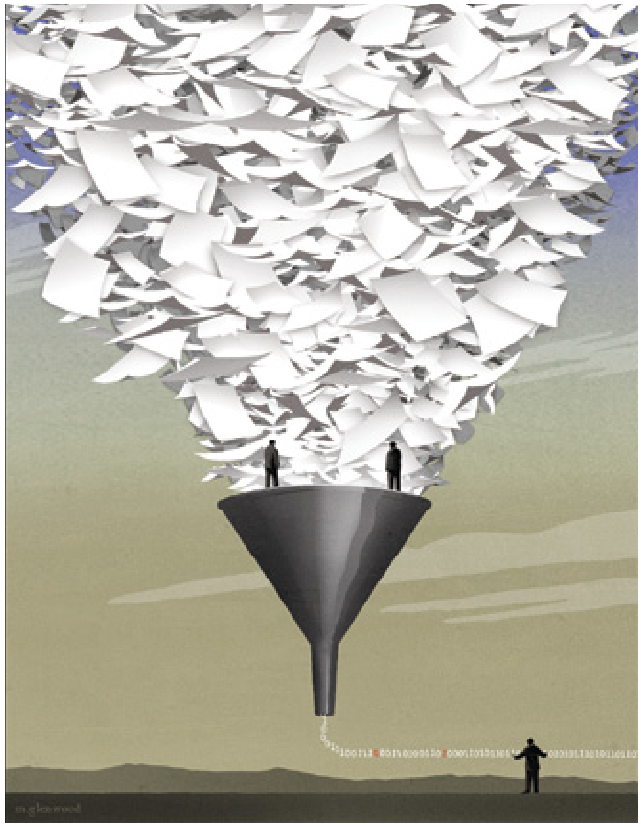
Data Glitches Are Hazardous to Your Health

Digital medical records can easily go awry, but nobody is tracking the errors



The first visit to a new doctor usually starts with yet another recitation of medical history. You recount your peanut allergy and Grandma's hypertension but forget to mention the medication you were on two years ago. Electronic health records are designed to circumvent such problems by providing an easily shareable record of all that information in one place.

The potential for greater convenience and accuracy is so clear that federal law requires doctors and hospitals to start using electronic records by 2015. More than half of all U.S. doctors already do so, up from only 17 percent five years ago. Almost four in five hospitals have made the transition to electronic records. The federal government has spent more than $15 billion to help promote the move.

For all their promise, however, electronic medical records have their own flaws. In dozens of known cases, caregivers have entered information into the wrong chart or listed important details—such as drug dosages—incorrectly. Data sometimes disappear. In one case, a patient's allergy to penicillin was improperly entered into an electronic record. The patient later received ampicillin and nearly died of shock.

Yet we have no idea how often these errors happen or how to make them stop because no centralized body is keeping track of the mistakes. We need to get a better idea of what is going wrong so that doctors and hospitals can try to fix the problems.

To that end, the U.S. Department of Health and Human Services should create a national safety board to collect data on e-record errors. It would receive anonymized information about medical mistakes and close calls and use this information to issue guidelines for the medical industry.

The board would operate much like the National Transportation Safety Board, the independent federal agency charged with leading hundreds of investigations a year into aviation accidents, highway crashes and pipeline leaks, among other incidents. When something goes wrong in the U.S. transportation system, board investigators identify the root causes and recommend concrete actions to ensure that the problem does not happen again. Their investigations have led to safety measures such as midair-collision-avoidance technology, a national drinking age of 21 and shoulder belts in the backseats of cars.

How would a national e-record-monitoring agency work? A few smaller-scale examples can serve as guides. Pennsylvania created a mandatory reporting system for all medical errors in June 2004. This system has uncovered thousands of e-record problems—from misreported laboratory tests to incorrect prescriptions. Almost 90 percent of these reports are close calls instead of adverse events, but still the data help to pinpoint what is causing the problem. In addition, some states in Australia also voluntarily report e-record errors, and the U.K. has been looking into a new system for its National Health Service.

The U.S. Department of Veterans Affairs, which cares for 8.76 million individuals, also tracks electronic errors on a voluntary basis. Its system provides only a partial snapshot of some trouble areas, but the agency takes its reported errors, analyzes them and, when necessary, sends out safety alerts to all users of its system.

Such systems cull data and funnel information to a centralized entity that can interpret it. And so it could be with a national e-record reporting system. Local institutions would have personnel fill out a standardized form when an error occurs, then file that report to a local and national reporting network.

The health department already faces a January deadline, set by Congress, to issue guidance on how to regulate health information technology. The department should take this opportunity to introduce a national database for electronic-record errors. Learning from these mistakes should ultimately save lives. Proper tracking can only help. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2013

Illustration by Michael Glenwood

Commentary on science in the news from the experts

J. P. Rangaswami is chief scientist of Salesforce.com, a fellow of the British Computer Society and of the Royal Society of Arts, and a trustee of the Web Science Trust. He writes the blog Confused of Calcutta.

Manufacturing, Hollywood-Style

In the not too distant future, the business of making things will require the skills, temperament and work flow of a good film crew

I love dictionaries. I like to sit and read them, immersed in the words that make up our own stories. That is how I first came across the original meaning of the word "manufacture."

The *Oxford English Dictionary,* in its primary, 17th-century, definition of the word, defines it as "the action or process of making by hand." Another definition from the 17th century reads: "Working with the hands; a manual occupation, handicraft."

These original meanings are mainly obsolete. Since the industrial revolution, we have associated the word "manufacture" with large-scale, centralized, machine-driven making of materials and goods. In the near future, however, every one of us will have the ability to make things at home, to manufacture things again—with our hands, using mechanical power and intellectual power in new ways. Printing in 3-D is going to take manufacturing back to its roots.

I was mesmerized when I saw my first 3-D printer in action back in the 1990s. The machining processes of traditional manufacturing were subtractive—paring, chiseling, grinding and filing—but 3-D printing is additive, building layer on layer. When I came across a method, based on 3-D printing, of correcting infant cleft palate, it took my breath away. Conventional surgery is invasive and painful to the point of barbarism, but the new technique promises a way for every child to soon have the right to smile.

Applications for 3-D printing have proliferated. They include the construction of "missing" pieces in jigsaw puzzles, screws and skull fragments; manufacture of body parts (initially bones and joints but recently body organs); production of new materials and chemicals; and manufacture of containers of various sizes, even entire buildings.

Soon manufacturing will start resembling the world of cooking. You can use raw ingredients, although that requires a high level of expertise. You can have someone else prepare the ingredients for you in advance or integrate the ingredients into prepared dishes or even for entire meals. Start to finish, the process can be done according to different levels of time, cost and quality. The specifications—the "recipes"—are where the real intellectual value is created. What can be combined and how, reliably, repeatably and safely? What alternatives and substitutions are possible? What can be modified for each instance?

If the creative process in manufacturing were all about recipes, what would the world look like? The new creators will be those who have access to the laboratories where they can safely experiment with different ways of manufacturing and verify the results before they are disseminated. Such facilities will have to cover a host of specialist experts, substance by substance, material by material, with the necessary knowledge of physics, chemistry, biology, electronics, design, social anthropology, law—the works. And they will have the tools and machines needed to experiment, iterate, learn, fix and reiterate until they attain the right levels of reliability, safety and affordability.

To invent this kind of process, we can draw on the experience of the film industry.

Instead of the lab, we have a studio. Instead of creative geniuses, we have stars. Instead of a variety of specialists, we have a production crew. Instead of a director and a producer to bring all these parts together, we have the people who lead the creative process and the financial investment.

The film industry knows about iteration. It knows about different genres of production. It knows about certification before public release. It knows about scripts, recipes—specifications.

The Hollywood we know wrote and directed the scripts of things we would then watch in large cinemas and later on in the comfort of our homes. There is a new Hollywood coming, where people write and publish the scripts for making things, which we as individuals and as collectives will follow. All of us will be able to bring back the original meaning of "manufacture," as we make things that feed us, keep us healthy, repair us and entertain us. SA

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Illustration by Skip Sterling

For people with a higher risk of stroke due to Atrial Fibrillation (AFib) not caused by a heart valve problem

I was taking warfarin. But I wondered, could I shoot for something better?

NOW I TAKE ELIQUIS® (apixaban) FOR 3 GOOD REASONS:

1. ELIQUIS reduced the risk of stroke better than warfarin.
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3. Unlike warfarin, there's no routine blood testing.

ELIQUIS and other blood thinners increase the risk of bleeding which can be serious, and rarely may lead to death.

Ask your doctor if ELIQUIS is right for you.

ELIQUIS is a prescription medicine used to reduce the risk of stroke and blood clots in people who have atrial fibrillation, a type of irregular heartbeat, not caused by a heart valve problem.

IMPORTANT SAFETY INFORMATION:

- **Do not stop taking ELIQUIS without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke.** ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.
- **ELIQUIS can cause bleeding which can be serious,** and rarely may lead to death.
- **You may have a higher risk of bleeding if you take ELIQUIS and** take other medicines that increase your risk of bleeding, such as aspirin, NSAIDs, warfarin (COUMADIN®), heparin, SSRIs or SNRIs, and other blood thinners. **Tell your doctor about all medicines, vitamins and supplements you take.** While taking ELIQUIS, you may bruise more easily and it may take longer than usual for any bleeding to stop.
- Get medical help right away if you have any of these signs or symptoms of bleeding:
  - unexpected bleeding, or bleeding that lasts a long time, such as unusual bleeding from the gums; nosebleeds that happen often, or menstrual or vaginal bleeding that is heavier than normal
  - bleeding that is severe or you cannot control
  - red, pink, or brown urine; red or black stools (looks like tar)
  - coughing up or vomiting blood or vomit that looks like coffee grounds
  - unexpected pain, swelling, or joint pain; headaches, feeling dizzy or weak
- **ELIQUIS is not for patients with artificial heart valves.**
- **Before you take ELIQUIS,** tell your doctor if you have: kidney or liver problems, any other medical condition, or ever had bleeding problems.

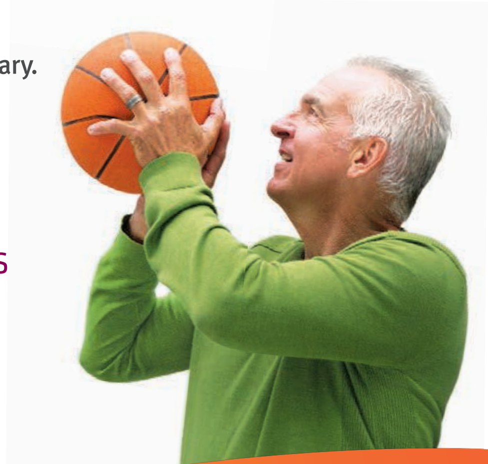
Tell your doctor if you are pregnant or breastfeeding, or plan to become pregnant or breastfeed.

- **Do not take ELIQUIS if you** currently have certain types of abnormal bleeding or have had a serious allergic reaction to ELIQUIS. A reaction to ELIQUIS can cause hives, rash, itching, and possibly trouble breathing. Get medical help right away if you have sudden chest pain or chest tightness, have sudden swelling of your face or tongue, have trouble breathing, wheezing, or feeling dizzy or faint.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch, or call 1-800-FDA-1088.

Please see additional Important Product Information on the adjacent page.

Individual results may vary.



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FACTS

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The information below does not take the place of talking with your healthcare professional. Only your healthcare professional knows the specifics of your condition and how ELIQUIS® may fit into your overall therapy. Talk to your healthcare professional if you have any questions about ELIQUIS (pronounced ELL eh kwiss).

What is the most important information I should know about ELIQUIS (apixaban)?

Do not stop taking ELIQUIS without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke. ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.

ELIQUIS can cause bleeding which can be serious, and rarely may lead to death. This is because ELIQUIS is a blood thinner medicine that reduces blood clotting.

You may have a higher risk of bleeding if you take ELIQUIS and take other medicines that increase your risk of bleeding, such as aspirin, nonsteroidal anti-inflammatory drugs (called NSAIDs), warfarin (COUMADIN®), heparin, selective serotonin reuptake inhibitors (SSRIs) or serotonin norepinephrine reuptake inhibitors (SNRIs), and other medicines to help prevent or treat blood clots.

Tell your doctor if you take any of these medicines. Ask your doctor or pharmacist if you are not sure if your medicine is one listed above.

While taking ELIQUIS:

- you may bruise more easily
- it may take longer than usual for any bleeding to stop

Call your doctor or get medical help right away if you have any of these signs or symptoms of bleeding when taking ELIQUIS:

- unexpected bleeding, or bleeding that lasts a long time, such as:
  - unusual bleeding from the gums
  - nosebleeds that happen often
  - menstrual bleeding or vaginal bleeding that is heavier than normal
- bleeding that is severe or you cannot control
- red, pink, or brown urine
- red or black stools (looks like tar)
- cough up blood or blood clots
- vomit blood or your vomit looks like coffee grounds
- unexpected pain, swelling, or joint pain
- headaches, feeling dizzy or weak

ELIQUIS (apixaban) is not for patients with artificial heart valves.

What is ELIQUIS?

ELIQUIS is a prescription medicine used to reduce the risk of stroke and blood clots in people who have atrial fibrillation.

It is not known if ELIQUIS is safe and effective in children.

Who should not take ELIQUIS?

Do not take ELIQUIS if you:

- currently have certain types of abnormal bleeding
- have had a serious allergic reaction to ELIQUIS. Ask your doctor if you are not sure

What should I tell my doctor before taking ELIQUIS?

Before you take ELIQUIS, tell your doctor if you:

- have kidney or liver problems
- have any other medical condition
- have ever had bleeding problems
- are pregnant or plan to become pregnant. It is not known if ELIQUIS will harm your unborn baby
- are breastfeeding or plan to breastfeed. It is not known if ELIQUIS passes into your breast milk. You and your doctor should decide if you will take ELIQUIS or breastfeed. You should not do both

Tell all of your doctors and dentists that you are taking ELIQUIS. They should talk to the doctor who prescribed ELIQUIS for you, before you have **any** surgery, medical or dental procedure.

Tell your doctor about all the medicines you take, including prescription and over-the-counter medicines, vitamins, and herbal supplements. Some of your other medicines may affect the way ELIQUIS works. Certain medicines may increase your risk of bleeding or stroke when taken with ELIQUIS.

How should I take ELIQUIS (apixaban)?

Take ELIQUIS exactly as prescribed by your doctor. Take ELIQUIS twice every day with or without food, and do not change your dose or stop taking it unless your doctor tells you to. If you miss a dose of ELIQUIS, take it as soon as you remember, and do not take more than one dose at the same time. **Do not run out of ELIQUIS. Refill your prescription before you run out. Stopping ELIQUIS may increase your risk of having a stroke.**

What are the possible side effects of ELIQUIS?

- See **"What is the most important information I should know about ELIQUIS?"**
- ELIQUIS can cause a skin rash or severe allergic reaction. Call your doctor or get medical help right away if you have any of the following symptoms:
  - chest pain or tightness
  - swelling of your face or tongue
  - trouble breathing or wheezing
  - feeling dizzy or faint

Tell your doctor if you have any side effect that bothers you or that does not go away.

These are not all of the possible side effects of ELIQUIS. For more information, ask your doctor or pharmacist.

Call your doctor for medical advice about side effects. You may report side effects to FDA at 1-800-FDA-1088.

This is a brief summary of the most important information about ELIQUIS. For more information, talk with your doctor or pharmacist, call 1-855-ELIQUIS (1-855-354-7847), or go to www.ELIQUIS.com.

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ASTROPHYSICS

A Cosmos of Particles

Neutrinos from deep space are opening up a new kind of astronomy

IceCube laboratory in Antarctica

COURTESY OF SVEN LIDSTROM *National Science Foundation*

The starry glow of the night sky brings news from the distant edges of the cosmos, as light fills astronomers' telescopes with the bizarre and wondrous processes in the universe. But light cannot tell the whole story—often it reveals only an object's superficial glow. To better understand the cores of powerful astrophysical objects, scientists are studying individual particles that can tell a firsthand tale of the extreme events that launch them outward at tremendous speed. A promising new frontier has just opened up that should bolster those investigations.

For more than a century now scientists have trapped particles known as cosmic rays to gather clues about the universe. Cosmic rays are charged particles (mostly protons) ejected by cosmic outbursts. Some have as much energy as a tennis ball served up at 90 miles per hour. Unfortunately, it is impossible to track a cosmic ray back to its source in the sky; magnetic fields twist the paths of charged particles into knots before those particles reach Earth.

The lightweight, neutral particles known as neutrinos do not have that problem. Neutrinos are famous for their ghostly behavior—they can emerge unmolested from the center of a violent outburst, zip straight across the universe and pass cleanly through Earth's atmosphere. Those qualities make neutrinos exquisite carriers of astronomical information. The trick is catching them once they arrive.

Scientists have constructed a giant neutrino detector, known as IceCube, a mile under Antarctic ice in the hopes of netting these astronomical neutrinos. And earlier this year the IceCube project announced that it had found 28 neutrinos so energetic that they must have come from outside the solar system. Two of the neutrinos, highlighted in a July study in *Physical Review Letters,* carry so much energy—hundreds of times that of the particles in the Large Hadron Collider—that affectionate astronomers have singled them out with names: Ernie and Bert.

As to what birthed these high-energy neutrinos, speculation abounds. They could have emerged from gamma-ray bursts, mysterious and short-lived cataclysms that briefly rank as the brightest objects in the universe; shock waves from exploding stars; or so-called blazars, jets of energy powered by supermassive black holes. Or Ernie and Bert may be the particle spawn of dark matter, the unidentified stuff that provides much of the universe's mass—or perhaps even a sign of more exotic phenomena.

In truth, scientists cannot glean much from a mere 28 particles. So far the high-energy neutrinos do not seem to point back to a specific source, which would give scientists more to go on. "Everybody's reading the tea leaves," says Francis Halzen, director of the IceCube Particle Astrophysics Center at the University of Wisconsin–Madison. But with IceCube expected to run for at least another decade, the era of particle astronomy is just beginning.

—Michael Moyer

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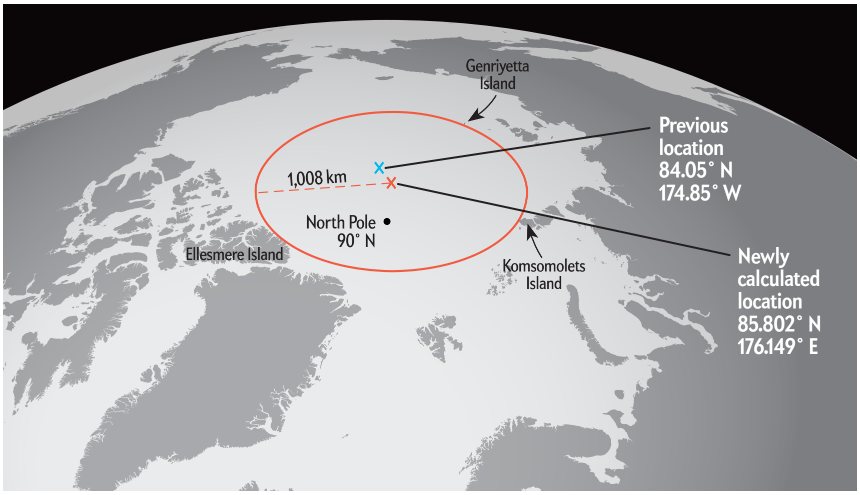


EXPLORATION

A New Race to Earth's End

Adventurers seeking the remotest place in the Arctic now have a new target. (But they'd better hurry—the ice is melting)

Of all the places on the surface of the earth, few are harder to reach than the appropriately named north pole of inaccessibility—the point on the Arctic Ocean that is farthest from land. From that place, a step in any direction across the shifting Arctic ice is one step closer to the relative safety of solid ground. The pole of inaccessibility has long been a tantalizing target for explorers. The late British adventurer Wally Herbert was said to have reached it by dogsled in 1968 while en route to the geographical North Pole, where all lines of longitude meet.

Recently polar explorer Jim McNeill was planning his own expedition when he noticed that old documents offered conflicting locations for the pole of inaccessibility. McNeill sought out a group of polar researchers, who decided to investigate for themselves. Drawing on NASA satellite imagery of the Arctic, they found that the spot long assumed to be farthest from land was off by 214 kilometers. Ted Scambos of the National Snow and Ice Data Center in Boulder, Colo., and his colleagues published the finding online in August in the journal *Polar Record*.

The scientists defined the pole as the center of the biggest circle that fits entirely within the Arctic Ocean. That circle meets shore at three points, each of them 1,008 kilometers from the newly determined pole. All three points happen to be on the shoreline of remote islands: on Canada's Ellesmere Island and Russia's Komsomolets Island and Genriyetta Island. "It's not like you're saved if you're stranded and manage to get to the closest landmass," Scambos says. "You'll be in trouble anywhere in that area."

What mistakes led to the erroneous location in the first place? Scambos and the others were unable to find an answer in the documents. Most likely some of the Arctic islands that are now well mapped were either unknown or ignored in the past. "But at least now the pole is defined," he says.

Given the change, Herbert's claim now appears to be invalid. "It really looks as though nobody has set foot on the pole," Scambos says. "Or if they did, they didn't know they were there." Thus, the race is back on to be the first person to reach the loneliest place in the Arctic. And the changing climate means that those who would attempt it on foot will have to contend with treacherous melting ice. "The area is a lot less safe than it was in the heroic time of exploration," he adds. "Of course, now an icebreaker could probably make it there a lot more easily."

—Arielle Duhaime-Ross

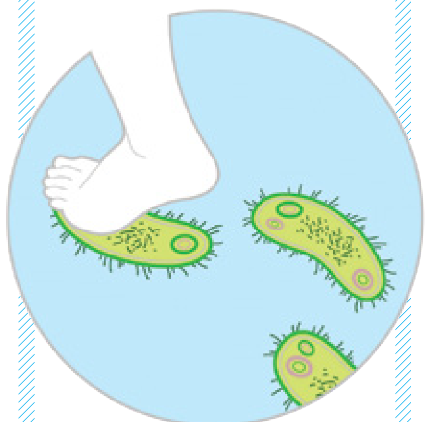
ENGINEERING

Reading Your Bacterial Aura

Unmasking tiny denizens of the great indoors

One cool day in Eugene, Ore., James Meadow, in a tank top and shorts, climbed inside a sealed, sterilized chamber—a former refrigeration unit affectionately called the "pickle box." The postdoctoral researcher at the University of Oregon's Biology and the Built Environment Center sat there for four hours, with no bathroom breaks, as 12 air filters collected the microorganisms emanating from his body.

"How much are humans giving off just sitting at the desk?" Meadow asks. He and his colleagues aim to find out.



The Oregon researchers keep tabs on what fills the air so they can design buildings that efficiently combine ventilation and filtration to surround occupants with the healthiest air possible. "If we're going to be constantly surrounded by bacteria," Meadow says, "we may eventually get to a point where we can manage the indoor ecosystem the same way that we manage national parks."

Preliminary data from the pickle box show that the assays can detect the presence of a single human and are beginning to pick out individual differences. For now, Meadow says, the built environment is uncharted ecological territory: "We know more about the bacteria that you find in deep ocean vents, or in the troposphere, or in rocks in Antarctica." *—Peter Andrey Smith*

Graphic by XNR Productions, Illustrations by Thomas Fuchs

Whirlpool galaxy

ASTRONOMY

Sayonara, Supergiant

A gigantic star in the Whirlpool galaxy has vanished, solving a supernova mystery

Every so often in the vast cosmos, something exciting happens in one of the few places that humans happen to watch closely. So it was with a recent supernova in the Whirlpool galaxy, a photogenic swirl some 30 million light-years away. Shortly after the light from an exploding star there reached Earth at the end of May 2011, amateur reports and images of the cataclysm began pouring in from around the globe.

Astronomers quickly determined that the supernova, SN 2011dh, resulted from the collapse of a massive star, but just what kind of star had met its end remained a mystery. As researchers sought to uncover exactly what had happened, the fact that the Whirlpool galaxy has

BY THE NUMBERS

1.6 million

Estimated number of U.S. smokers who tried to quit after seeing the Centers for Disease Control and Prevention's Tips from Former Smokers ad campaign. The 2012 ads used graphic imagery and personal stories to focus on the dire health risks of smoking.

Number of smokers who likely succeeded in quitting long-term, according to a recent study published by CDC researchers in the *Lancet*.

100,000

COURTESY OF NASA (*galaxy*); SOURCE: "EFFECT OF THE FIRST FEDERALLY FUNDED U.S. ANTISMOKING NATIONAL MEDIA CAMPAIGN," BY TIM McAFEE ET AL., IN *LANCET*. PUBLISHED ONLINE SEPTEMBER 9, 2013 (*smoking statistics*)

COMMENT AT ScientificAmerican.com/nov2013

long captured astronomers' attention once again came in handy. The Hubble Space Telescope had scanned the galaxy in detail in 2005, and a comparison of those images with the 2011 images revealed that at the very spot of the supernova, an unremarkable yellow supergiant star once sat.

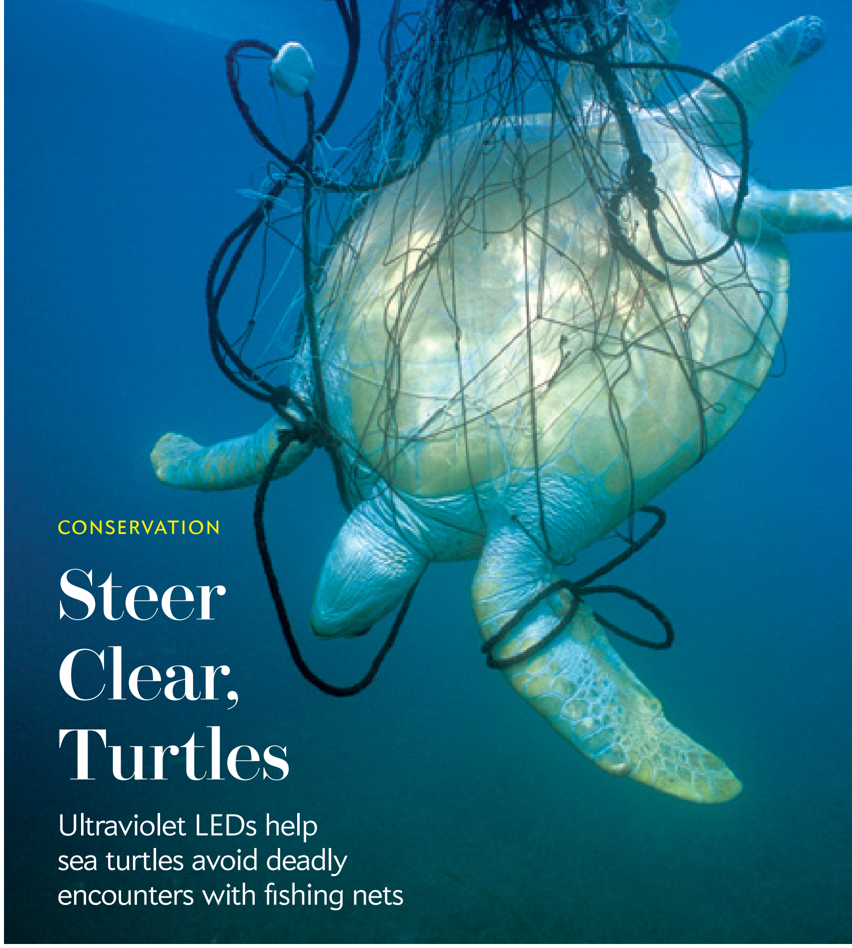
Yet some researchers found that the supernova appeared much cooler than would be expected from the collapse of such an enormous star. Instead their early data pointed to the demise of a smaller, bluer star—perhaps a close neighbor of the yellow supergiant. "The yellow star was hiding the bluer star that actually exploded—that was our conjecture," says astronomer Schuyler Van Dyk of the California Institute of Technology.

A competing team, however, had arrived at a different conclusion. Justyn Maund, now at Queen's University Belfast, and his colleagues hypothesized that the yellow star Hubble had spotted was indeed the one that exploded. But in 2011 no one could say for certain who was right—the brilliant glow of the supernova obscured the area in question.

By this past March the supernova had faded significantly, and Van Dyk and his colleagues commandeered Hubble to take another look. To their surprise, the yellow supergiant star had vanished, indicating that it had produced the supernova after all. "The other team was actually correct," says Van Dyk, lead author of a study reporting the findings in *Astrophysical Journal Letters*.

Yet the saga of the supernova will not end there. SN 2011dh turned out to be a rare type IIb supernova, which results from the collapse of a massive star that has been stripped of most of its hydrogen shell, perhaps caused by the pull of a companion star. If that explanation is correct, the supergiant's surviving partner should still exist. And as the bright blemish of the supernova remnant continues to fade, that survivor should reveal itself to Hubble toward the end of the year.

—John Matson



CONSERVATION

Steer Clear, Turtles

Ultraviolet LEDs help sea turtles avoid deadly encounters with fishing nets

Every decade fishers looking to catch tuna, shrimp, snapper and other marine creatures unintentionally pull millions of sea turtles out of the oceans, according to one recent estimate, most of them vulnerable to extinction. This kind of accidental capture, researchers believe, is a leading cause of sea turtle mortality.

Because banning fishing altogether would do serious harm to local economies, conservationists have instead sought ways to warn sea turtles away from fishing nets. Studies have shown that the turtles can perceive light across the visible spectrum as well as into the ultraviolet, whereas the visual sensitivity of many fish drops off just before the UV range. "When we compare the visual spectrums, there's this disparity between what turtles and fish see," says John Wang, a fisheries researcher at the University of Hawaii at Manoa. "That means there's a selective communication channel in the UV range where we could perhaps communicate to turtles but not to fish."

Wang and his colleagues teamed up with fishers in Baja California Sur, Mexico, to experiment with reusable, battery-powered UV LEDs as a turtle deterrent. By securing UV lights at five-meter intervals on fishers' gill nets, they reduced accidental sea turtle capture, or bycatch, by around 40 percent, as compared with control nets with inactivated LEDs, the team recently reported in *Biology Letters*. Although the illuminated nets trapped slightly fewer fish than the control nets, the researchers found no significant difference in the financial value of the two catches.

The fishers, Wang says, were initially reluctant to participate in the research but soon "came to realize that we're not trying to save turtles at the expense of fishing communities." In the long run, such technologies might even save fishers money. "Turtles wreak havoc on gear, so in some places [communities] have a strong incentive to implement bycatch-reduction solutions," says Hoyt Peckham, a visiting scholar at Stanford University's Center for Ocean Solutions, who was not involved in the research. The LEDs currently cost about two dollars each, but the price is dropping.

Potentially, Wang adds, it may be possible to use LEDs emitting different wavelengths of light to scare off turtles while luring in commercially desirable species. He plans to test that idea over the coming year in Mexico, Brazil and Indonesia.

—Rachel Nuwer

JEFF ROTMAN *Getty Images*

COMMENT AT ScientificAmerican.com/nov2013

HEALTH

What's Better Than BMI?

The flawed body mass index remains a useful predictor of health

How much can one simple number tell you about your health? A growing body of research over the past few years has highlighted the shortcomings of the body mass index (BMI), a basic measure of rotundity, as a predictor of well-being. The latest—and in some ways most comprehensive—of these reports appeared in August in the journal *Science.*

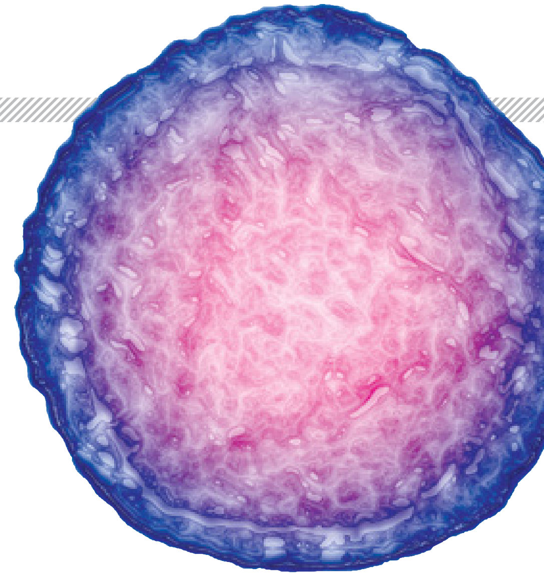
The BMI formula, developed in the 1800s by a Belgian statistician and sociologist, divides a person's weight, in kilograms, by the square of his or her height, in meters. As the new study points out, a normal BMI can mask metabolic abnormalities; even people with a normal weight-to-height ratio can harbor disorders in the way the body handles nutrients. Increasingly, researchers are documenting the many ways a metabolic condition called insulin resistance, for example, elevates the risk for heart disease, Alzheimer's disease and other ailments. According to a 2008 analysis, nearly one in four people with a normal BMI were metabolically unhealthy.

Conversely, an elevated BMI does not necessarily reflect poor metabolic health. About half of overweight individuals are metabolically normal. In recent years Katherine Flegal of the U.S. Centers for Disease Control and Prevention and her colleagues have found that people in the overweight (but not obese) BMI category tend to live longer, as a group, than folks in the normal BMI range. Flegal cautioned against overinterpreting the results, however. After all, there is no way for a few BMI groupings to account for the diversity of bodies.

Take, for instance, the location of excess body fat. Fatty deposits around the abdomen are much more hazardous than fat under the skin of the arms or legs. Some researchers think it makes sense to incorporate a third measurement to better classify body types. Waist circumference, along with height and weight, yields the so-called ABSI (a body shape index), for which numerous calculators are available online.

But there is no need to ditch BMI, which is still a decent approximation of health risk for most people. The point is that good health depends on a lot of things—physical fitness, diet, smoking, and even our surroundings and the company we keep—many of which cannot be quantified.

—Christine Gorman



FORENSICS

Mutating Viruses Lead Cops to the Criminals

Forensic epidemiologists are tracking rapid viral mutations to help convict criminal spreaders of disease

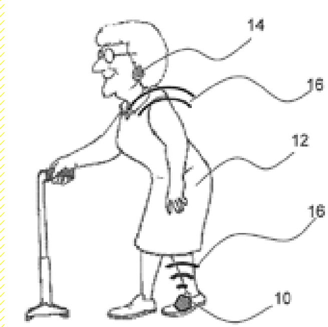
In May 2012 a hospital in small-town Exeter, N.H., notified the state of a possible cluster of linked hepatitis C cases. Four people had recently been diagnosed, and testing soon revealed that the genetic codes of the strains that they carried were nearly identical. Because hepatitis C virus (HCV) mutates rapidly, epidemiologist Jose Montero knew that the infections most likely originated from the same person. "We knew we needed to find this person immediately," says Montero, the state's director of public health.

The four also shared a common history—three had been patients at Exeter Hospital's Cardiac Catheterization Laboratory, and one worked there. As the investigators began testing former laboratory patients, they identified 29 more cases. By sequencing the genomes of the viruses in the outbreak, Montero's colleagues at the state's Public Health Laboratories constructed an evolutionary tree that led back to lab employee David Kwiatkowski. Police believe Kwiatkowski injected himself with the clinic's narcotics and reused the needles on patients.

More and more, scientists are helping to solve crimes using molecular techniques originally designed for epidemiology—tracking the spread of disease through large populations. In a similar application of forensic epidemiology, Fernando González Candelas of the University of Valencia helped to retrace an even larger outbreak in Spain, where an anesthesiologist was suspected of spreading HCV to hundreds of patients.

Candelas's group compared the genomes of viruses contracted in the outbreak with those of other HCV strains circulating in Valencia. The researchers found that people sickened in the outbreak carried a virus that was significantly closer to the anesthesiologist's strain of HCV than anything going around in the community, indicating that the doctor had almost certainly infected them.

PATENT WATCH

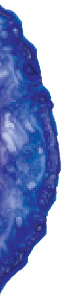


Method and device to manage freezing of gait in patients suffering from a movement disorder: Imagine walking down the hall, when suddenly your legs refuse to take another step. Up to 60 percent of people with Parkinson's disease regularly experience such freezing of gait (FOG) episodes, which can lead to falls and serious injuries. "Some patients describe the feeling as having their feet glued to the floor," says Emil Jovanov, a professor of computer and electrical engineering at the University of Alabama in Huntsville. Current treatments are not always effective, so Jovanov and his colleagues are developing a device that alleviates FOG with sensory cues, which have been shown to improve symptoms.

Patent no. 8,409,116 describes the device, which relies on sensors that might be embedded in a shoe or attached to the ankle. As soon as the system senses a freeze-up, it wirelessly transmits an auditory cue (such as the word "walk") to an earpiece, prompting the patient to keep moving. The device is still in development, but the researchers hope to bring it to market in the next few years. *—Sophie Guterl*

JAMES CAVALINI *Science Source (hepatitis virus)*; COURTESY OF U.S. PATENT AND TRADEMARK OFFICE *(woman with cane)*

COMMENT AT ScientificAmerican.com/nov2013



Candelas and his colleagues were also able to estimate when a person became infected to confirm that the infection occurred while that person was under the doctor's care.

The researchers recently published in *BMC Biology* the details of their inquiry, which in 2007 helped to convict the anesthesiologist of infecting 275 people. "People can live with HCV for a long time and infect large numbers of people," Candelas says. "The only way we can prove that they are the source of the infections is through forensic epidemiology."

Despite the widening use of epidemiology in the courtroom, it has its limitations. In one critique, two researchers noted that viral reconstructions involve a degree of interpretation and estimation. They cautioned that jurors may place unwarranted confidence in the science "and fail to comprehend or fully engage with its complexities and inherent shortcomings."

The New Hampshire hepatitis case never reached a jury. After Montero worked with the FBI to build a criminal case that uncovered a trail of HCV infections and drug infractions across several states, Kwiatkowski pled guilty in August. Although Montero cannot say with certainty why Kwiatkowski accepted a plea deal, "I'd like to believe it was on the strength of our epidemiological investigation."

—*Carrie Arnold*

BY THE NUMBERS

$54 million

Cost of the CDC's 2012 Tips from Former Smokers ad campaign. The ads cost roughly $200 for every year of life saved, as estimated by CDC researchers.

BASIC RESEARCH

Wanted: Science Sugar Daddy

Once unfettered labs seek financial shelter

The Marine Biological Laboratory in Woods Hole, Mass., has long been known for its prodigious output of basic science research on marine animals. For 125 years the MBL has been on a relatively short list of independent labs without a university affiliation. Researchers at these institutes can focus more on discovery than on teaching or other duties, and the institutes themselves are often very specialized, thereby leading to outsize contributions to science.

The independence of the MBL and other labs is quickly eroding. Most of the MBL's operating budget comes from merit-based federal grants, but that could soon change. In June the lab tapped a new funding stream by allying itself with the deep-pocketed University of Chicago. The MBL will retain its own identity, but it remains to be seen how the university's priorities will mesh with the lab's traditional focus and strengths.

The MBL's struggles stem from financial woes at the National Institutes of Health. In the past decade the budget for the country's primary scientific funding arm has stagnated and even declined. Acceptance rates for grant applications have dropped precipitously as a result. More acutely, this year's federal budget sequestration is cutting more than $1.5 billion and about 700 new research grants from the NIH. Small, freestanding labs in particular are feeling the crunch.

The Boston Biomedical Research Institute shut down last year after a sharp drop in NIH funding. Fox Chase Cancer Center in Philadelphia, primarily financed by patient care revenue and research grants, was bought by Temple University.

Such deals run the risk of spoiling the freewheeling, innovative culture of the small labs, some critics say. "It is a challenge to merge the independent research institute with a university system in a way that preserves a creative atmosphere," says Greg Patterson, president of the Association of Independent Research Institutes. —*Dave Levitan*

COURTESY OF CELESTE LeCOMPTE

OUTREACH

Tattoos, Ponytails and Protozoans

Scientists haul their wares to Burning Man

Ever since Lake Lahontan dried up thousands of years ago, the Black Rock Desert in Nevada has been a forbidding habitat. The flat terrain is covered with a white alkaline powder, and dust storms are frequent. That has not deterred revelers at the annual Burning Man festival, however. This year they have come bearing water fleas, tardigrades and other creatures that would have been more at home in the Pleistocene lake.

"Ohhhhh, there's one!" Mariya Levina, wearing a lab coat over a bikini top and shorts, her pink hair pulled back in a ponytail, is peering into one of four microscopes arranged on a folding table. She is looking at a trumpet-shaped protozoan, *Stentor,* as it lurches to a halt on the slide.

The mobile science exhibit, known as the MicroZoo, is the brainchild of bioengineer Tristan Ursell, a postdoctoral scholar at Stanford University. He aims to reconnect visitors, for whom science classes may be a distant (or even unpleasant) memory, with the wonder of biology. "There's a whole world just out of view," Ursell says. "I want people to think about that."

At another microscope, an iPad screen displays a magnified specimen of human skin. A group of young, tattooed men begins zooming in on different parts of the sample, posing questions about what they are seeing.

The MicroZoo is just one manifestation of science on the playa. The Phage, a 100-plus-member "theme camp," hosts nightly talks on topics ranging from stem cells to 3-D modeling. Burning Man may be known more for parties and sculpture pyrotechnics, but by attending, "people allow themselves to be curious," Ursell says. "They're open to trying new things."

—*Celeste LeCompte*

ENERGY

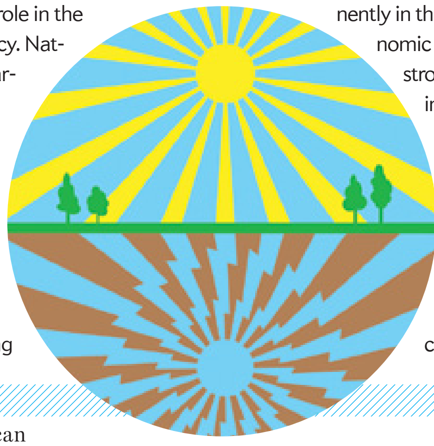
Obama's Fracking Dilemma

Opposition complicates the White House plan to move toward clean energy

In theory, fracking can be done safely and cleanly. In practice, the firms that do the work of pumping chemically treated water into the ground to crack shale and free natural gas have made an environmental mess. The political backlash is now making it difficult for the Obama administration to sell its plan to move the nation toward greater use of cleaner energy.

The administration's ongoing woes were evident in August, when U.S. energy secretary Ernest J. Moniz addressed an audience at Columbia University. Hecklers hounded him as pro-fracking. They have a point. Fracking plays a big role in the White House's all-of-the-above energy policy. Natural gas would serve as a bridge to a low-carbon future, full of electricity from sunshine, wind and fission, as well as fossil fuels.

The White House has been trying to shrink emissions from coal-fired power plants, which emit more carbon dioxide than comparable power plants using other fuels. In September the Obama administration mandated cuts in CO_2 emissions from coal plants, after previously announcing up to $8 billion in new loans for "clean coal" projects. These include investments in carbon capture and storage, which would deposit CO_2 deep underground, where it would not contribute to climate change. Despite the sweeteners, the coal industry has not taken kindly to these policies, which have been derided, Moniz said, as "tantamount to a war on coal."



If clean coal stalls and fracking opponents succeed in slowing the flow of natural gas, electricity will have to come from somewhere else. Nuclear power, another source that figures prominently in the administration's plans, faces stiff economic headwinds from cheap natural gas and strong public opposition in light of the ongoing Fukushima disaster. If two new nuclear reactors now under construction in Vogtle, Ga.—the first built in the U.S. in more than three decades—go over budget that would "seriously cloud the future" for U.S. nuclear power, Moniz said. And any shortfall in natural gas and nuclear would most likely come from coal—not the clean kind. *—David Biello*

Q&A

A Is for App

Children in rural Ethiopia are teaching themselves to read with Android tablets

PROFILE

NAME
Maryanne Wolf

TITLE
Director, Tufts University Center for Reading and Language Research

LOCATION
Medford, Mass.

You and your colleagues are designing a tablet-based system to help children learn the basics of literacy. Where have you tested it so far?
There are two villages in Ethiopia: Wonchi and Wolonchete. There were 20 kids in each village to begin, between four and 12 years old. They are very, very poor. In Wolonchete they walk 2.5 hours to get water and 2.5 hours back. These are children who live too far away to be taught in school, who have never been exposed to English. There are no literate members of either village and no electricity. The villagers provided the space and helped to build solar-powered charging stations.

The children have had the tablets for about a year to a year and a half. I went about five months ago to Ethiopia to personally assess them. Most of the kids knew half or more of the English words that we tested. We found that two young girls and one boy who had assumed the role of teacher went through all the hoops—these three knew all the letters, could write them, give the name of any letter in any completely randomized array. These three children also knew a lot of letter sounds and were able to recognize very common words.

What technologies are you using?
We are using Android on the Motorola Xoom so we can enter data and constantly get data from it, which we can't do on an iPad. We chose the apps out of a huge number having something to do with language development, precursors of reading, things like understanding that something can have a rhyming sound. We were also able to use videos from certain television programs, such as *Between the Lions*. We listed every single word from every single app, and we know how many times the kids have heard a particular word or how many times they have tapped that word.

What roadblocks do you see for wider implementation?
We're not as worried about cost as we would have been three years ago. But in One Laptop per Child, they learned that the devices have to be robust because of the heat and dust. You can't have devices breaking down all the time—that's just technological detritus. *—Ferris Jabr*

COURTESY OF ALONSO NICHOLS *Tufts University*

COMMENT AT ScientificAmerican.com/nov2013

WHAT IS IT?

The insect* Issus coleoptratus *cannot fly, but it can certainly jump. The diminutive bug belongs to the taxonomic grouping Fulgoromorpha, commonly known as the plant hoppers. When researchers noticed that the legs of *I. coleoptratus* move within 30 microseconds of perfect synchrony, it became clear that the insects have more than just a spring in their step. In fact, they have gears at the base of their legs, as biologists in the U.K. revealed with a scanning electron microscope.

The plant hopper is the first animal known to grow functional, interlocking gears on its body, which synchronize the propulsive thrusts of the insect's hind legs. The researchers published the discovery in September in *Science.*

The gear mechanism appears to have a limited window of usefulness. As *I. coleoptratus* transitions from a nymph to an adult, its gears disappear. The insect's liftoffs actually get faster with age as it develops different jumping techniques, leaving the gears behind like a set of cast-off training wheels. —*Rachel Feltman*

COURTESY OF MALCOLM BURROWS (*insect detail*); DON JOHNSTON *Getty Images* (*fox*)

BY THE NUMBERS

$96 billion

Additional health care costs incurred by smokers in the U.S. every year, according to the CDC. Smoking-related productivity losses to employers are even greater.

INFECTIOUS DISEASE

Woodland Menace

What's to blame for the startling prevalence of Lyme disease?

The fear of ticks, and of the Lyme disease these bloodsuckers carry, is well founded: roughly 30,000 cases of Lyme are reported to the U.S. Centers for Disease Control and Prevention every year. Because most cases go unreported, the true toll is more like 300,000, the CDC estimated in August. The new figure "confirms that Lyme disease is a tremendous public health problem," Paul Mead, the CDC's chief of Lyme epidemiology and surveillance, said at the time.

As investigators struggle to explain Lyme's prevalence, some have shifted focus from the long-maligned deer that carry adult ticks to a smaller culprit. The white-footed mouse, which hosts immature ticks, is especially efficient at passing the Lyme-causing bacterium *Borrelia burgdorferi* from one generation of ticks to the next.

The mouse is also an opportunist that thrives where other species cannot. As human development fragments forests into smaller patches, white-footed mice increase in density even as other animals disappear. "It is an animal weed," says Felicia Keesing, a professor of biology at Bard College. "Anything that causes a surge in the population of these mice is something to watch." Predator removals can cause just such a surge. A 2012 study found that Lyme incidence in recent decades coincided not with deer abundance but with declines in the population of red foxes, which eat mice and other small mammals.

Testing ideas about Lyme in the wild is exceedingly difficult. As a result, some researchers contend that the best protection is a diverse animal population that controls or dilutes the effects of white-footed mice. Others argue that targeting deer, which allow ticks to reproduce, remains the better strategy. In the meantime, as researchers debate the relative importance of the species implicated in Lyme disease, *B. burgdorferi* is doing just fine. —*Shraddha Chakradhar*

Gambling on the Brain

Addictive drugs and gambling rewire neural circuits in similar ways

When Shirley was in her mid-20s she and some friends road-tripped to Las Vegas on a lark. That was the first time she gambled. Around a decade later, while working as an attorney on the East Coast, she would occasionally sojourn in Atlantic City. By her late 40s, however, she was skipping work four times a week to visit newly opened casinos in Connecticut. She played blackjack almost exclusively, often risking thousands of dollars each round—then scrounging under her car seat for 35 cents to pay the toll on the way home. Ultimately, Shirley bet every dime she earned and maxed out multiple credit cards. "I wanted to gamble all the time," she says. "I loved it—I loved that high I felt."

In 2001 the law intervened. Shirley was convicted of stealing a great deal of money from her clients and spent two years in prison. Along the way she started attending Gamblers Anonymous meetings, seeing a therapist and remaking her life. "I realized I had become addicted," she says. "It took me a long time to say I was an addict, but I was, just like any other."

Ten years ago the idea that someone could become addicted to a habit like gambling the way a person gets hooked on a drug was controversial. Back then, Shirley's counselors never told her she was an addict; she decided that for herself. Now researchers agree that in some cases gambling is a true addiction.

In the past, the psychiatric community generally regarded pathological gambling as more of a compulsion than an addiction—a behavior primarily motivated by the need to relieve anxiety rather than a craving for intense pleasure. In the 1980s, while updating the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM*), the American Psychiatric Association (APA) officially classified pathological gambling as an impulse-control disorder—a fuzzy label for a group of somewhat related illnesses that, at the time, included kleptomania, pyromania and trichotillomania (hairpulling). In what has come to be regarded as a landmark decision, the association moved pathological gambling to the addictions chapter in the manual's latest edition, the *DSM-5,* published this past May. The decision, which followed 15 years of deliberation, reflects a new understanding of the biology underlying addiction and has already changed the way psychiatrists help people who cannot stop gambling.

More effective treatment is increasingly necessary because gambling is more acceptable and accessible than ever before. Four in five Americans say they have gambled at least once in their lives. With the exception of Hawaii and Utah, every state in the country offers some form of legalized gambling. And today you do not even need to leave your house to gamble—all you need is an Internet connection or a phone. Various surveys have determined that around two million people in the U.S. are addicted to gambling, and for as many as 20 million citizens the habit seriously interferes with work and social life.

TWO OF A KIND

THE APA BASED ITS DECISION on numerous recent studies in psychology, neuroscience and genetics demonstrating that gambling and drug addiction are far more similar than previously realized. Research in the past two decades has dramatically improved neuroscientists' working model of how the brain changes as an addiction develops. In the middle of our cranium, a series of circuits known as the reward system links various scattered brain regions involved in memory, movement, pleasure and motivation. When we engage in an activity that keeps us alive or helps us pass on our genes, neurons in the reward system squirt out a chemical messenger called dopamine, giving us a little wave of satisfaction and encouraging us to make a habit of enjoying hearty meals and romps in the sack. When stimulated by amphetamine, cocaine or other addictive drugs, the reward system disperses up to 10 times more dopamine than usual.

Continuous use of such drugs robs them of their power to induce euphoria. Addictive substances keep the brain so awash in dopamine that it eventually adapts by producing less of the molecule and becoming less responsive to its effects. As a consequence, addicts build up a tolerance to a drug, needing larger and larger amounts to get high. In severe addiction, people also go through withdrawal—they feel physically ill, cannot sleep and shake uncontrollably—if their brain is deprived of a dopamine-

Illustration by Logan Faerber

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stimulating substance for too long. At the same time, neural pathways connecting the reward circuit to the prefrontal cortex weaken. Resting just above and behind the eyes, the prefrontal cortex helps people tame impulses. In other words, the more an addict uses a drug, the harder it becomes to stop.

Research to date shows that pathological gamblers and drug addicts share many of the same genetic predispositions for impulsivity and reward seeking. Just as substance addicts require increasingly strong hits to get high, compulsive gamblers pursue ever riskier ventures. Likewise, both drug addicts and problem gamblers endure symptoms of withdrawal when separated from the chemical or thrill they desire. And a few studies suggest that some people are especially vulnerable to both drug addiction and compulsive gambling because their reward circuitry is inherently underactive—which may partially explain why they seek big thrills in the first place.

Even more compelling, neuroscientists have learned that drugs and gambling alter many of the same brain circuits in similar ways. These insights come from studies of blood flow and electrical activity in people's brains as they complete various tasks on computers that either mimic casino games or test their impulse control. In some experiments, virtual cards selected from different decks earn or lose a player money; other tasks challenge someone to respond quickly to certain images that flash on a screen but not to react to others.

A 2005 German study using such a card game suggests problem gamblers—like drug addicts—have lost sensitivity to their high: when winning, subjects had lower than typical electrical activity in a key region of the brain's reward system. In a 2003 study at Yale University and a 2012 study at the University of Amsterdam, pathological gamblers taking tests that measured their impulsivity had unusually low levels of electrical activity in prefrontal brain regions that help people assess risks and suppress instincts. Drug addicts also often have a listless prefrontal cortex.

"For most people gambling is expensive entertainment. But for some it's a dangerous product. You really can get addicted."

Further evidence that gambling and drugs change the brain in similar ways surfaced in an unexpected group of people: those with the neurodegenerative disorder Parkinson's disease. Characterized by muscle stiffness and tremors, Parkinson's is caused by the death of dopamine-producing neurons in a section of the midbrain. Over the decades researchers noticed that a remarkably high number of Parkinson's patients—between 2 and 7 percent—are compulsive gamblers. Treatment for one disorder most likely contributes to another. To ease symptoms of Parkinson's, some patients take levodopa and other drugs that increase dopamine levels. Researchers think that in some cases the resulting chemical influx modifies the brain in a way that makes risks and rewards—say, those in a game of poker—more appealing and rash decisions more difficult to resist.

A new understanding of compulsive gambling has also helped scientists redefine addiction itself. Whereas experts used to think of addiction as dependency on a chemical, they now define it as repeatedly pursuing a rewarding experience despite serious repercussions. That experience could be the high of cocaine or heroin or the thrill of doubling one's money at the casino. "The past idea was that you need to ingest a drug that changes neurochemistry in the brain to get addicted, but we now know that just about anything we do alters the brain," says Timothy Fong, a psychiatrist and addiction expert at the University of California, Los Angeles. "It makes sense that some highly rewarding behaviors, like gambling, can cause dramatic [physical] changes, too."

GAMING THE SYSTEM

REDEFINING COMPULSIVE GAMBLING as an addiction is not mere semantics: therapists have already found that pathological gamblers respond much better to medication and therapy typically used for addictions rather than strategies for taming compulsions such as trichotillomania. For reasons that remain unclear, certain antidepressants alleviate the symptoms of some impulse-control disorders; they have never worked as well for pathological gambling, however. Medications used to treat substance addictions have proved much more effective. Opioid antagonists, such as naltrexone, indirectly inhibit brain cells from producing dopamine, thereby reducing cravings.

Dozens of studies confirm that another effective treatment for addiction is cognitive-behavior therapy, which teaches people to resist unwanted thoughts and habits. Gambling addicts may, for example, learn to confront irrational beliefs, namely the notion that a string of losses or a near miss—such as two out of three cherries on a slot machine—signals an imminent win.

Unfortunately, researchers estimate that more than 80 percent of gambling addicts never seek treatment in the first place. And of those who do, up to 75 percent return to the gaming halls, making prevention all the more important. Around the U.S.—particularly in California—casinos are taking gambling addiction seriously. Marc Lefkowitz of the California Council on Problem Gambling regularly trains casino managers and employees to keep an eye out for worrisome trends, such as customers who spend increasing amounts of time and money gambling. He urges casinos to give gamblers the option to voluntarily ban themselves and to prominently display brochures about Gamblers Anonymous and other treatment options near ATM machines and pay phones. A gambling addict may be a huge source of revenue for a casino at first, but many end up owing massive debts they cannot pay.

Shirley, now 60, currently works as a peer counselor in a treatment program for gambling addicts. "I'm not against gambling," she says. "For most people it's expensive entertainment. But for some people it's a dangerous product. I want people to understand that you really can get addicted. I'd like to see every casino out there take responsibility." SA

Ferris Jabr is an associate editor at Scientific American.

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2013

David Pogue is the personal-technology columnist for the *New York Times* and host of NOVA's *Making Stuff* on PBS this fall.

Crash Text Dummies

Hands-free apps attempt to make it safer for drivers to send text messages. They fail

The most interesting developments in technology are never the gadgets themselves. It's how they impact society.

Even decades into the cell-phone revolution, for example, we're still trying to figure out how to fit them into our lives. What *are* the rules for making phone calls in public places? For e-mail during meals? And above all, for using them in cars?

Recently I wrote about Motorola's new Moto-X cell phone. Like most smartphones today, you can control it by voice: have it read new text messages aloud (and dictate replies), check your e-mail, dial a number for you. But this phone goes a step further: to indicate that you're about to issue a spoken command, you don't even have to press a button. You just say, "Okay, Google Now." The phone is always listening. You never have to touch it or even look at it.

Clearly, that's a step toward greater safety, I concluded. You can leave the phone in your car's cup holder—never take your hands off the wheel, never take your eyes off the road.

Many readers, however, were aghast. "You're promoting the fallacy that when driving, speaking to a cell phone is safer than having to use a hand to manipulate it," wrote a typical one. "Studies tell us that hands or no hands, eyes on the screen or on the road, using a cell phone while driving causes more accidents than does the abuse of alcohol or drugs. What were you thinking?!"

I was thinking that it *must* be safer to send texts hands-free. After all, you have to look at the screen to type. If you're looking down at your phone, you're driving a two-ton projectile, blind, at 65 miles an hour.

Besides, the studies referred to by my readers examined *talking* on the phone—hands-on or hands-free. As we now know, those two methods are equally dangerous. It's not holding the phone that causes accidents—it's mental distraction. (In that regard, the 11 states with hands-free laws are wasting their time.)

But these studies do not address the subject at hand here: the safety of *voice* texting versus *manual* texting.

Clearly, people will still text behind the wheel, no matter how much we preach against it, no matter how many states ban it (41 so far). It's like the programs that distribute condoms to teenagers or clean needles to drug addicts: yes, we'd like it better if teenagers didn't have sex or addicts didn't shoot up. But some will anyway. So isn't it better to make their unfortunate activities as safe as possible?

And then something happened that changed my mind. For the first time, researchers finally compared hands-free texting with *hands-on* texting.

The Texas A&M Transportation Institute studied people driving a closed course under three conditions: while texting by hand, while texting by voice (using Siri for iPhone and Vlingo for Android), and without texting at all.

The results surprised me—and troubled me. Turns out it makes absolutely no difference whether you text hands-free or by voice. "Response times were significantly delayed no matter which texting method was used," the study says. In each case, drivers who were texting took about twice as long to react as they did otherwise. Incredibly, they also spent less time watching the road, even when they were texting by voice.

It doesn't make intuitive sense. It *seems* as though texting by voice should be safer than looking at your phone. And to be sure, this was only a single study, involving only 43 subjects.

But if this study's results reflect reality, I'll say it right here in print: I was wrong.

We already knew that hands-free phone conversations are just as dangerous as hands-on, and now we know the same thing about texting by voice. You shouldn't text at all while driving. Your teenagers shouldn't. I shouldn't.

And I've endorsed voice-activated texting for the last time. SA

SCIENTIFIC AMERICAN ONLINE
More on the science of driver distraction: ScientificAmerican.com/nov2013/pogue

Illustration by Sam Washburn

Guide to Professional Science Master's

in collaboration with naturejobs

Masters of industry

Science programs prioritizing business needs over basic research careers are bringing fairytale outcomes

Science career paths in the United States have a "Goldilocks" problem. Bachelor of Science degrees are "too small"—inadequate for employers' requirements. PhDs are "too big"—taking too long to complete and focusing disproportionately on academia-oriented research rather than real-world applications. Over the last decade, a "just right" degree—the Professional Science Master's—has been developed.

The Professional Science Master's (PSM) has grown from a handful of pilot programs sponsored by the Alfred P. Sloan Foundation (see 'Unexpected origins') to more than 300 courses now affiliated by the PSM National Office.

The degrees are often referred to as "hybrid masters", because they combine the scientific focus of a traditional master's with the business skills of an MBA, a combined skill set companies say is lacking in trained scientists at all levels.

The programs, which usually take around two years to complete, appeal to recent Bachelor of Science graduates who want a career in science, but don't want to commit years to a PhD and postdoc, as well as those already in employment looking to boost their skills. PSM programs affiliated with the PSM National Office are subject to new standards which require a strict balance between scientific and soft skills. The bedrock of PSM programs remains scientific, with a mandatory minimum of 50 percent of credits in science. A further 20 percent of the PSM credits must come from courses that teach business skills like accounting or marketing and "soft skills" such as communication. Additionally, affiliated PSMs require some kind of experienced-based project, whether it is a group consulting project or an internship.

Unlike PhDs, PSM programs don't offer funding through teaching or research assistantships and students tend to pay for their own tuition, but many PSM alums regard that tuition as a good investment since their training helps to jump-start their careers.

Jeff Graybill, a senior project manager at California-based biotech firm Amgen, is an alum of one of the first PSM programs, at the Keck Graduate Institute (KGI) in Claremont, California. During the program, he interned with a KGI professor who was spinning out a company, Ionian Technologies, and stayed on after graduation. "I basically created a job for myself," Graybill says. His transition to Amgen was made easier because the company was represented on KGI's PSM advisory board.

PHOTO COURTESY OF UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

The campus at the University of Illinois at Urbana-Champaign.

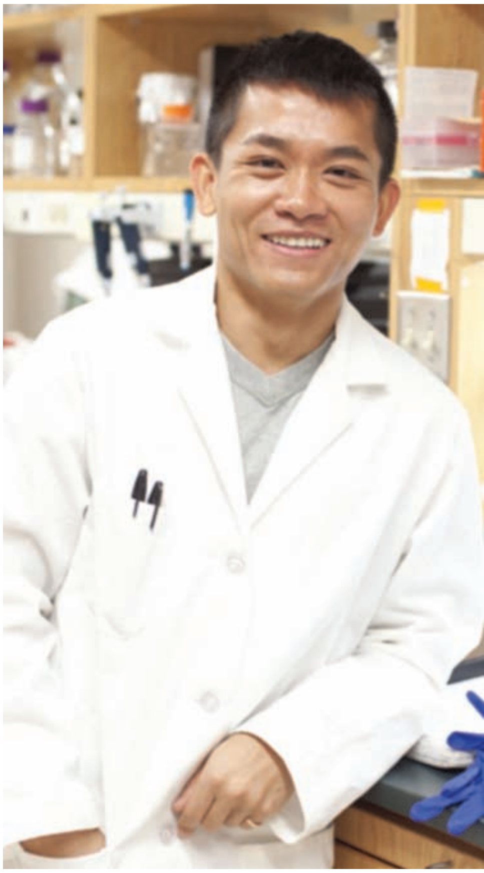
Linked in

Perhaps the most beneficial aspect of the program is its connection, through host institutions, to industry, says Jim Sterling, director of the PSM National Office and VP for Academic Affairs at KGI. All affiliated PSM programs are developed with input from the business community. For instance, most programs have advisory boards, whose members may help guide, evaluate and even hire the program's students—both as interns and as employees. The quantity and quality of such partners can make or break a program, because they provide a training and placement network. "That network defines the strength of the program," Sterling says.

Before joining a program, Sterling recommends students ask program directors about the companies they work with: "Do the sponsors come back year after year? Do you actually see them on campus? Do the students have an opportunity to interact with them?" he says. Graybill's role, now senior manager in global operations planning at Amgen, is proof of the value of these business networks. "One of the people on the KGI advisory board was from Amgen. Some people I knew passed my name along," says Graybill. "That's why I am here."

It is also worth investigating which business partners participate in curriculum development and find out what roles they play. At Rice University, corporate affiliates provide feedback on the curriculum, and then faculty members develop it based on that input. For example, the energy company Chevron works closely with Rice University's engineering PSM program. Jerry Rovner, a consulting engineer in Chevron's Energy Technology Company, helps develop the curriculum, place interns and judge student projects. "My job is to see that the coursework is a good fit for companies like

> "Companies consistently ask us to provide training in more professional skills."
>
> Jim Sterling, director of the PSM National Office and VP for Academic Affairs at Keck Graduate Institute



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THE RIGHT FIT?

Since the PSM emerged 15 years ago for scientists to train for industry careers, flexibility has been a hallmark of the degree. All courses affiliated with the National Professional Science Master's Association, in conjunction with the Council of Graduate Schools, require a solid science core, a number of 'plus' courses and some form of work experience. But other elements vary, including curriculum, class and program completion time. Here are a few factors to consider.

Full-time versus part-time

Location and discipline plays a role in the level of time required. For example, the PSM agri-business programs at the University of Illinois at Urbana-Champaign are a full-time commitment.

At Rutgers University, on the other hand, students are encouraged to get additional work experience while also taking classes – many of which are offered nights or weekends to accommodate working students.

Time to completion

Depending on work experience requirements and whether the program is taken full or part-time, completion can vary from a little over a year to around three years. Silver says most Rutgers PSM students need two or more years, whereas the engineering PSM at Northeastern University can be completed in a year, without an internship. But people who are in the program for professional development take one course at a time, evenings or weekends, and require a longer stint, says Sara Wadia-Fascetti, a Northeastern engineering professor involved with the university's engineering PSM programs.

Virtual or real

Some programs offer geographic flexibility and a mix of real and virtual instruction, while others keep it local. The home of Northeastern University is in Boston, but it offers PSMs from regional campuses in Charlotte and Seattle and offers a hybrid of face-to-face and online instruction, says Wadia-Fascetti.

Others, like Buffalo State University's data analysis and mathematical modeling PSM program, focus on face-to-face interaction, says Joaquin Carbonara, the program's director, which allows for industry guest speakers, site visits and workshops.

Rigid or flexible

Carbonara keeps his program adaptable by structuring it as a series of one-credit evening courses. Those shorter courses were recommended by industries the university surveyed while developing the program and they make the curriculum easier to "plug and play", says Carbonara. In other words, instructors can more easily tweak lesson parts, or scrap courses entirely, as the industry changes.

This means the course stays relevant, says Rutgers' Silver. "If I were a student, I would want to be in a program that was affiliated and that was keeping up with what industry wants."

For example, David W. King, director of the SUNY Professional Science Master's Consortium, noticed that courses in regulatory affairs were among the most useful in biotech and drug discovery programs but not quite right for programs on medical devices, which have different regulations set by the FDA. So they quickly set up webinars on medical device regulation to meet the needs of students.

COURTESY OF KECK GRADUATE INSTITUTE

PSM students at Keck Graduate Institute make a presentation as part of their Team Master's Projects (TMPs) in which teams of three to six students work with sponsoring companies to solve real problems.

Chevron," Rovner says.

And Chevron is just one company in a network of hundreds, primarily in the Houston area, connected to Rice's PSM program. This network leads to jobs, says Dagmar Beck, director of Rice University's Professional Master's Programs in Science and Engineering: "All of our students have found employment."

At Case Western Reserve University in Ohio, the PSM programs draw heavily upon 'CEO in Residence' Bruce E. Terry, former president and CEO of manufacturing firm Mayfran International. The curriculum centers on entrepreneurship, so Terry's experience as an angel investor and an intellectual property hunter feed directly into the program and he often brings guest speakers and lecturers from the investment and start-up community. Ed Caner, Case Western's PSM director, says that prospective PSM students should examine a program's advisory boards—but also ask about the board members' level of involvement. "An advisory board is only useful if it is active," he says.

Enrolling in a PSM will also give you a valuable network of peers who will be climbing career ladders alongside you. Kevin Sightler, director of University of Illinois at Urbana-Champaign's agribusiness-related PSMs says that the program's graduates have created

> "It is important to understand all the various people in a company that speak a slightly different language. If you can speak in a way that they are comfortable with it can really help your career."
>
> Jeff Graybill, senior project manager, Amgen

UNEXPECTED ORIGINS

Sometimes unintended consequences are the best. When the Alfred P. Sloan Foundation helped pioneer Professional Science Master's degrees fifteen years ago, there were concerns that the new degrees would cannibalize the pipeline to PhD programs. In fact, the opposite is true.

Many alums who wouldn't have gone on to do graduate work have enrolled in PSM programs and some decide to pursue basic research rather than applied. The pipeline from academia to industry has improved. And some of the value-added education of PSMs—particularly training in communication, presentation and basic business management skills (see main story)—have migrated directly into some PhD programs or are being adapted into workshops by scientific professional societies.

When Sheila Tobias co-wrote *Rethinking Science as a Career* in 1995, academic jobs in science were so scarce that many PhDs were considering changing fields. The authors had no idea that the book would help launch a whole new degree.

PhD students interviewed for the book repeatedly expressed regret about lacking skills like business fundamentals, computer science and writing, Tobias says. She realized the gap represented a curriculum. "They were telling us what they needed to be more competitive outside academia," she says.

She found career options after a B.S. were "limited" and that professors at graduate programs tended to steer their students toward research careers, despite a dearth of faculty positions. The business leaders she interviewed said that STEM graduates they wanted to hire didn't have the interpersonal skills necessary for success in industry.

Tobias thought the M.S. could be tailored to offer more professional skills as well as science training. The M.S. was often considered a consolation prize for a failed PhD bid, she says.

The book led to what Tobias calls a "Sloan call" when the foundation offered funding for her to look into a small set of pilot programs. She contacted science deans from around the US to send questionnaires to people who either didn't get into their PhD program or didn't complete it.

The Sloan Foundation and several institutions she called upon as possible pilot projects were all receptive and thinking along the same lines, says Tobias.

The Sloan Foundation took on the PSM approach in part because the US science pipeline appeared to be leaky. "So many people major in science and math and so few go on," says Michael Teitelbaum, a demographer and senior adviser with Sloan.

The PSM helps filter more US-trained scientists into the workforce, without, perhaps flooding the graduate school ranks. "They offer a graduate level pathway to a science career," says Teitelbaum. "It is not really a competitor to the PhD/postdoc path," he adds, "it is a necessary addition."

JAMIE SMITH, UNIVERSITY OF ILLINOIS

PSM students take part in an innovation workshop at the University of Illinois at Urbana-Champaign.

an informal network to help each other find jobs. The NPSMA are now working to formalize such alumni networks.

Still Scientific

The next element of PSM programs to consider, says Sterling, is the quality of the curriculum. It should teach a good balance of scientific and business skills. He says some programs sacrifice some of the science content to improve professional components.

Available programs cover the range of science disciplines from physical to life sciences, as well as chemistry, computer science, engineering and math. Biotech and pharmaceutical programs are the most common and most aim to prepare students for the private sector. But some programs, in fields like national defense and environmental science could also qualify students for the government or nonprofit sector.

The ideal program provides excellent scientific training in one's chosen discipline, and offers several 'plus' skills like project

> "I would definitely recommend a PSM for someone not looking forward to going into an academic environment. It's a great way to link your undergraduate education to the needs of the corporate world."
>
> Diana Wolf, Finance Rotation Associate, Capital One bank

management, marketing and presentation, says Bogdan Vernescu, head of mathematics at the Worcester Polytechnic Institute and president of the National Professional Science Master's Association (NPSMA), which organizes best-practices workshops and guidance on launching PSM programs. A PSM should also cover the theoretical and applied side of the discipline. In the financial math PSM program supervised by Vernescu, students take courses in both the math and business departments. "The students need to understand both the mathematics and the business side of the investments or portfolio management," Vernsescu says.

An emphasis on science is integral at Stony Brook University's scientific instrumentation PSM, with courses in both classical and quantum physics. Harold Metcalf, the program's director, says they make sure students are "physicists first". Having that background gives the students "a leg up", because acumen in accounting and statistics is gained more easily after the rigorous quantitative science courses.

To ensure that science was at the forefront of its PSM programs, Rutgers University in New Jersey, took a standard 30-credit science Master's, added six business

CASE STUDIES

After Diana Wolf earned her Bachelor of Science in mathematics from the University of Florida in 2009, she was unclear about her options. "The problem with pure math programs is they lead you to a PhD," says Wolf. "I didn't want to be a professor or a researcher. I wanted to learn more about industry."

Wolf enrolled in a PSM program in financial mathematics at Worcester Polytechnic Institute and besides helping her learn how she could apply mathematics to real-world situations, the program gave Wolf the skills she uses every day in role as Finance Rotation Associate at Capital One bank – especially communication and cooperation skills. "In many classes I had to give presentations one-on-one to my professors and to the whole class," she says. "We also had to do a lot group work, which is how things are done in the real world."

Wolf says the internship she took during the program validated her decision to eschew academia for industry. "It definitely made me realize my skill sets and what I enjoy more," she adds. "I do enjoy the business side of things."

"I would definitely recommend a PSM for someone not looking forward to going into an academic environment," Wolf says. "It's a great way to link your undergraduate education to the needs of the corporate world."

From the industry viewpoint, Jerry Rovner at Chevron sees what PSM recipients can bring to the company. He says that traditional B.S. degrees don't prepare many students for today's workforce. "People are educated, but we can't find the skills we need."

The firm looks for people who can understand the language of science and business and can also handle project management. "There is a lot of business sense that goes into a project as well as the technical side," Rovner says.

The PSM offers Chevron what it needs for entry and mid-level employees, he says: "a firm technical background with business skills."

Rice's PSM program is such a good fit for Chevron that the company placed a dozen interns and made offers to all of them.

courses, and replaced a thesis with a team project, says Deborah Silver, executive director of its PSM program. Some standard Master's comprise a set of classes that don't necessarily fit together. She got involved with Rutgers' PSM program because she wanted to help create a degree with a set of classes that "tells a story."

Plus points

'Plus' courses help tell companies the story that PSM graduates will be a good fit, says Sterling. "Companies consistently ask us to provide training in more professional skills," he says. It's not just the content of these courses in subjects like ethics, communication, presentation, accounting, and product development, that are important, Sterling maintains, but how they are taught – often with guest lectures and workshops with industry leaders. Projects within those courses almost invariably require teamwork and culminate in a presentation that is often judged by industry experts from the school's advisory board.

Both the content and the method of learning at KGI appealed to Graybill. "The business classes were great," he says, because they taught him the languages of people he might interact with in a working environment, like the accounting terms used by a chief financial officer. "No one in our program was likely to become a chief financial officer," says Graybill. "It was more important to understand the CFO, and all the various people in a company that speak a slightly different language. If you can speak in a way that they are comfortable with it can really help your career."

In at the deep end

Perhaps the best industry interaction a PSM can provide is an internship that leads to a job. In some programs internships are mandatory, others just recommend them. Some will help place students, while in others the onus is on individuals to find a placement. Checking to see what help students can expect when it comes to landing an internship is one way of assessing the value of tuition investment.

Students completing a PSM with an affiliated institution must complete some form of work experience—but there is scope for taking on new roles with an existing employer, doing an internship, or taking part in a 'capstone' project—which means working with a group of students as a consultancy for a company.

Besides being a conduit for a full-time job, Graybill's internship provided him with "pretty incredible" business experience because it meant creating a company out of one KGI professor's intellectual property. "I got to work on a business plan on the ground floor."

In Rice University's engineering PSMs, the program's advisory board members, like Chevron's Rovner, are very involved in the internship process – from placement to evaluation. "We go to the students' presentations and interact with them both before and after their internships." At these talks, Rovner says, he sees the benefits of taking communication courses. "I am rather envious of their presentation skills," he says.

Since Case Western's PSM emphasizes entrepreneurship, students get involved in early-stage companies. "Our students either work for start-ups or for an economic development group that supports start-ups," says Caner. "They do everything from technology feasibility analysis to market research or investigating whether there is a market sector that is missing."

Rutgers' PSM programs allow some flexibility, since many of its students work at least part-time. Some take on traditional internships, while other students do their internship at their existing place of employment, but in a different department, or performing a different role.

Students at Stony Brook's scientific instrumentation program are instructed quite simply for their work experience, says Metcalf. They are told: "Go into a laboratory and build something that works". Students first approach a faculty member and ask what needs to be built to perform experiments that they don't already have. The professor then tells the students under what conditions the device needs to work and what data it should produce. "The faculty says, 'Here are the specs'," says Metcalf. As part of their thesis, the students may often write a manual on how to use the device.

COURTESY OF KECK GRADUATE INSTITUTE

The campus at Keck Graduate Institute.

> "If I were a student, I would want to be in a program that was affiliated and that was keeping up with what industry wants."
>
> Deborah Silver, Rutgers University

At KGI, which offered one of the first five PSM programs, students do both an internship and a Team Master's Project (TMP). The two are designed to be complementary, says Craig Adams, KGI's TMP director. The internship comes before the TMP and tends to focus on science and technology. The project emphasizes business skills.

Doing both an internship and a TMP puts students in touch with more potential employers–increasing the odds of a job when they finish the program. For Marc Doble, who did a biotech PSM at KGI, meeting many potential employers – through guest teachers, networking events, TMPs or internships – justified the time and expense of a PSM. "It gives you a defined runway when you start job hunting," he says. Doble, who roomed with Graybill when they both were in KGI's first biotech PSM cohort, took off from that runway, flew with the science and business skills he learned, and ultimately landed a job with Amgen. For Graybill and Doble, choosing a PSM turned out to be "just right".

The Scientific Life

Hear the story of a life in science from a researcher who started as a graduate student studying beta-carotene in bacteria, and became director of an institute trying to solve issues of world hunger. Learn about the hypotheses that have powered the science throughout, and the experiments and findings behind them.

Theoretical Physics

Speaker: Frank Close, Ph.D.

Antimatter: Facts and Fiction

The Big Bang produced matter and antimatter in equal amounts, yet there is very little antimatter in our universe. Where has all the antimatter gone? Could antimatter solve the world's energy problems, or even make the ultimate weapon of mass destruction? The answer to both questions is no — learn why.

Nothing: Mysteries of the Vacuum

If you take away the Earth, moon and stars, what remains? The concept of the void — nothing — has alarmed and fascinated humans from the dawn of time. We'll move from the philosophical speculations of early civilizations to the cutting edge thinking of modern science to ask: Can we understand nothing?

Neutrino: Ghost Particle of the Cosmos

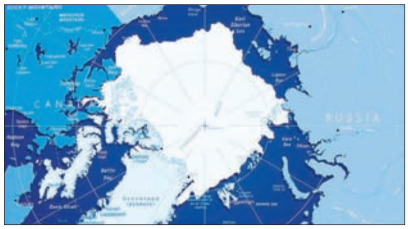
Ghostly neutrino particles stream through Earth by the billions as if it wasn't there. This is the story of how these extraordinary particles were sought and found — a story of heroic endeavor, of lifetimes spent chasing the near-impossible — and the scientific revelations neutrinos have enabled.

A Lopsided Universe

Nature produces structured asymmetric patterns prolifically: Even human life is lopsided, with spherical embryos somehow giving rise, ultimately, to creatures whose inner organs are asymmetric. This is the story of a quest for the origins of structure in nature, which has culminated in the discovery of the Higgs Boson particle.

The Story of the Higgs Boson

Roughly 50 years ago a new theory of the basic structure of matter was inspired by the work of Peter Higgs and others. In July 2012, Higgs's boson was finally found. Hear the story behind this amazing discovery, and delve into the ideas that inspired it.



History of Science

Speaker: Edward Larson, Ph.D.

Scientific Exploration of the Arctic

Scientists and geographers knew virtually nothing about the Arctic until 150 years ago, when Fridtjof Nansen and his protégé Roald Amundsen became legends by exploring this mysterious territory. While cruising through the beginning of the Arctic in Scandinavia, we'll follow their exploits as they opened the Arctic for science.

Amundsen, Scott, and Science in the Antarctic

The Antarctic was a mystery to humanity until the Royal Society-backed expeditions of Robert Scott and Ernest Shackleton, followed by Roald Amundsen's entry in the field. We'll follow the adventure and the science of the early research at the South Pole.

The Evolution Controversy

Creationism has changed, creationists say, but has it? Rooted in supposed biblical truths, almost by definition creationism cannot evolve, but creationist tactics do. We'll explore the world of modern creation science, intelligent design, and the 21st-century American battle over teaching evolution.

The Neo-Darwinian Synthesis

Charles Darwin was central to the story of modern evolutionary theory, but he wasn't its founder. We'll trace this grand breakthrough from Lamarck and the dawn of evolutionary science through Darwin to the modern neo-Darwinian synthesis of the 1930s, when genetics finally explained how evolution operated.

Robotics

Speaker: Alan Winfield, Ph.D.

Robotics: The State of the Art

Robots are moving out of factories and into homes, hospitals and offices. Robots are now mobile and working alongside humans. We'll delve into the state-of-the-art in intelligent robotics, defining what a robot is through examples from current research. Learn how the latest robots differ drastically from earlier generations.

A Brief History of Robotics

Trace the history of robotics from Classical Greece to the modern day, from Aristotle's early reference to the idea of an intelligent tool that could replace human labor, to Leonardo da Vinci's programmable automata, and W. Grey Walter's 1940s robot "tortoises," regarded as the first autonomous electronic mobile robots.

Robot Ethics

Like any transformative technology, intelligent robotics has the potential for huge benefit, but is not without ethical or societal risk. We'll explore whether there are situations where robots should be banned, and the issue of whether intelligent robots themselves could or should be ethical.

The Thinking Robot

Could robots ever truly think like humans, or have feelings? We'll explore how intelligent present-day intelligent robots really are, and the future prospects of designing robots that not only have increased abilities, but also have a sense of self.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

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Plan to visit the Pushkin Museum, the Hermitage Museum, and Peterhof Palace.

For more info please email Concierge@InsightCruises.com or visit ScientificAmerican.com/travel

EVOLUTION

King of Beasts

Africa once harbored a far greater variety of large carnivores than it does today. Competition with early humans for access to prey may have brought about their decline

By Lars Werdelin

Illustration by David Palumbo

Lars Werdelin is senior curator of fossil vertebrates at the Swedish Museum of Natural History in Stockholm. His research focuses on African carnivores and the relation between their evolution and that of humans.

Sunrise on the Serengeti,

and life on the savanna is in full swing. Zebras and wildebeests graze the dewy grass; elephants and giraffes munch on acacia leaves; and lions and hyenas survey the scene, looking for their next meal. To visit this place is, in some ways, to see the world as it looked to our ancestors millions of years ago, long before humans began to wreak havoc on the planet—or so the conventional wisdom goes. Indeed, much of eastern Africa is often thought of as a pristine ecosystem, largely unchanged by our kind in the more than two million years since our genus, *Homo,* arose.

But new research paints a rather different picture of this supposedly unaltered place. In my studies of the fossil record of African carnivores, I have found that lions, hyenas and other large-bodied carnivores that roam eastern Africa today represent only a small fraction of the diversity this group once had. Intriguingly, the decline of these carnivores began around the same time that early *Homo* started eating more meat, thus entering into competition with the carnivores. The timing of events hints that early humans are to blame for the extinction of these beasts—starting more than two million years ago, long before *Homo sapiens* came on the scene.

The rise of this new meat eater—and the loss of the big carnivores—would have triggered large-scale changes farther down the food chain, affecting the prey animals and even the plants those creatures ate. Thus, if my hypothesis is correct, our forebears began radically transforming ecosystems far earlier than previously thought, at a time when ancestral population sizes were quite small. *Homo,* it seems, has been a force of nature from the outset.

VANISHED CARNIVORES

FOSSIL CARNIVORES—WHICH IS TO SAY, members of the Carnivora order of mammals—have captivated me ever since I first read about them in the books of Finnish paleontologist Björn Kurtén as a teenager. Back then, I just thought they were cool, and I knew that they played an essential role as regulators of herbivore populations, which would explode without these predators to keep them in check. Only after I began studying carnivore fossils professionally, however, did I come to appreciate how their relationship with humans has evolved over millions of years.

For two decades I have studied thousands of carnivore fossils from eastern and southern Africa, trying to get a handle on how the modern carnivore community evolved over the past seven million years. I have conducted much of this research in collaboration with Margaret E. Lewis of Richard Stockton College, who is an expert on carnivore bones from the neck backward, whereas I specialize in their teeth and skulls. Our work has yielded a much higher-resolution view than was previously available of how many kinds of carnivores there were in Africa at different times during this interval, which also spans the entire known history of human evolution. As we amassed more and more data, we gained a much clearer picture of the species that thrived and failed over time, and we began to realize that the decline of the large carnivores (those weighing 21.5 kilograms or more) coincided with a shift among human ancestors from a mostly vegetarian diet to one that relied more heavily on animal foods. To our great surprise, it looked as though our early

IN BRIEF

Millions of years ago Africa's large carnivores were much more diverse than they are today, both in terms of the number of species that existed and of the ecological roles they played.

Fossil analyses show that the decline began more than two million years ago, around the same time that early members of our genus, *Homo,* started eating more meat.

The timing suggests that competition with humans for access to prey may have driven large carnivores to extinction, potentially triggering a cascade of other ecological changes.

ancestors might have been at fault for the loss of these species.

Snapshots of a few key fossil sites provide a sense of the transformation the African carnivore community underwent. The carnivores from the early part of this seven-million-year interval were nothing like the ones found today. Fossils dating to between 7.5 million and five million years ago from the site of Lothagam on the western shore of Lake Turkana in northern Kenya reveal sabertooth cats, strange long-legged hyenas, giant bear dogs (neither bears nor dogs but members of an extinct family of carnivores, the Amphicyonidae), and a leopard-size member of the mustelid family to which badgers belong. Smaller carnivores related to today's civets and mongooses also prowled there.

By four million years ago a familiar face had joined the carnivore cast. At the nearby site of Kanapoi, sabertooths and other now extinct lineages were still present, but the most common carnivore there was a hyena species ancestral to the brown hyena found in southern Africa today. Fast-forward another few hundred thousand years, and the carnivore community is even more recognizable. The 4.4-million- to 3.6-million-year-old site of Laetoli in the Serengeti of Tanzania, famed for its fossilized trail of footprints belonging to hominins (members of the human family), has remains of modern-looking cats along with the sabertooths. Early spotted hyenas, several dog species, a giant civet and a variety of smaller carnivores lived there, too. At Hadar in Ethiopia, the final resting place of the 3.2-million-year-old Lucy skeleton, sabertooths, hyenas and dogs abound, along with giant otters that have no modern counterpart.

These and other sites in the time range of four million to 2.5 million years ago all tell the same story. Each has a slightly different mix of carnivore species, depending on the environmental setting, but all have the same general kinds of carnivores. For example, all the sites have hyenas, but they differ in the species of hyena that lived there. And more important, none indicates that these animals were any worse off as a result of the presence of hominins.

After peaking around 3.5 million years ago, the number of large carnivore species declined gradually over the next million and a half years or so, mostly because the rate at which new species originated slowed down while the extinction rate held steady. Still, on the whole, the big carnivores reigned supreme during this time; our small, slow, defenseless ancestors were merely food. But the tide was about to turn.

The record after two million years ago shows unmistakable changes in the composition of carnivore communities. With extinction rates increasing and origination rates remaining low, the number of large species began to nosedive, particularly after 1.5 million years ago. Not only did individual species die out, but entire groups of species, such as the sabertooth cats, disappeared. As these beasts of yore declined, modern species—including the lions, leopards and jackals that inhabit Africa today—came to account for an ever increasing proportion of carnivore communities. By around 300,000 years ago the archaic carnivore lineages had all been winnowed out in eastern Africa and the modern carnivore community was in place.

A WOLF IN SHEEP'S CLOTHING

The general pattern Lewis and I observed in our data fit with our intuitive understanding of the evolutionary history of African carnivores in that it confirmed that there were more kinds of large carnivores in the past than there are today. What we had not anticipated was the steep downturn after 1.5 million years ago. It was this timing that hinted our *Homo* ancestors might be at fault.

For the first few million years of human evolution, hominins were relatively small-brained, chimpanzee-size creatures that subsisted primarily on plant foods. But by 1.5 million years ago a new kind of hominin was on the scene—one that was bigger, smarter and armed with stone tools. This was *Homo erectus* (sometimes called *Homo ergaster*), the first member of the human family to really look like us—and the first to start eating much in the way of meat. Perhaps, Lewis and I reasoned, competition with this human predator, which was incorporating increasing amounts of animal protein from large herbivores into its diet, could explain the carnivore decline.

That explanation seemed promising, but the timing of the events nagged at me. If competition with *H. erectus* was to blame, then the steep decline in eastern Africa's large carnivore species should have started well before 1.5 million years ago because *H. erectus* had emerged by nearly 1.9 million years ago. Species numbers are a blunt instrument at best for tracking the progress of an entire order of mammals over time because a reduction in numbers of one of its group can be masked by an increase in another. If two sabertooth species go extinct but are replaced by lions and leopards, the numbers will remain the same, but the community will have undergone a major change because lions and leopards can take a broader range of prey than sabertooths could.

It occurred to me that I could get a better sense of what had befallen the large carnivores if I understood not just how many species there were at any given time but how diverse their ecological roles were. Carnivores vary a lot in how they make a living. The cats, for example, are highly adapted to eating meat and thus qualify as hypercarnivores. But other carnivores are omnivorous—dogs, for example, will eat a wide variety of food in addition to meat. Still others, such as raccoons, are hypocarnivores, eating very little meat and subsisting mainly on fruits and vegetables.

I decided to build on work of my former postdoctoral student Gina D. Wesley-Hunt, now at Montgomery College, who had investigated the evolution of North American carnivores over the past 60 million years. As part of her study, Wesley-Hunt identified a set of traits related to the function of the jaws and teeth of carnivores. By studying these traits, she could quantify just how different species in a single carnivore community were from one another in terms of the kinds of foods they ate and hence their ecological roles. Using the fossil-coding scheme she developed to identify the function of the jaws and teeth (that is, the eating preferences they had evolved for), I coded 78 carnivore species—29 large and 49 small—from the African fossil record of the past 3.5 million years. I then analyzed the data, looking at how the number of different kinds of carnivores with different ecological roles living within the same community changed over time.

To visualize the diversity of form and inferred eating preferences in these fossil carnivores, I plugged the data from the coding scheme into a statistical analysis, thereby creating a two-dimensional plot that I call the morphospace. This morphospace represents the diversity of form (and inferred function) that exists within a group of related organisms, in this case the carnivores that lived in Africa over the past 3.5 million years. Plotting separate morphospaces for carnivores from distinct time intervals and comparing them offers a sense of how carnivore anatomy and eating habits shifted over time.

The results proved startling. As Lewis and I reported in March in *PLOS ONE,* it turns out that large carnivores that live in eastern Africa today occupy only a small fraction (less than 1.5 percent) of the morphospace of the carnivores in the 3.5-million- to three-million-year interval, when species diversity was at its highest. The group has lost nearly 99 percent of its so-called functional richness, which is to say today's carnivores fill far fewer kinds of ecological roles than their predecessors did. Moreover, the measured decrease in this functional richness began in the interval between two million and 1.5 million years ago, which means that the process must have started before that time—bringing the onset of this major decline in line with the origin of *H. erectus*. Although our work focused on carnivores from eastern Africa, modern large carnivores are basically the same across the continent. Thus, it is likely that the loss of functional richness we found in this region is representative of what happened to all of Africa's large carnivores.

Human activity is not the only possible cause of this loss of Africa's carnivores. Climate change has been implicated in many faunal changes in Africa over the course of the past few million years, and at first glance comparisons of climate and species numbers imply it is a front-runner in this case as well. Studies of modern carnivore species, however, suggest that the influence of climate on the functional richness of modern carnivore communities is slight. In general, carnivores are insensitive to climate and related environmental change, unlike mammalian herbivores, which are dependent on the distribution of plant food, which in turn is largely determined by climate. Furthermore, if climate change was the culprit, then the smaller carnivores should have declined, too—but they did not. Both the species richness and functional richness of the small carnivores have held up over most of the past 3.5 million years and may even have increased.

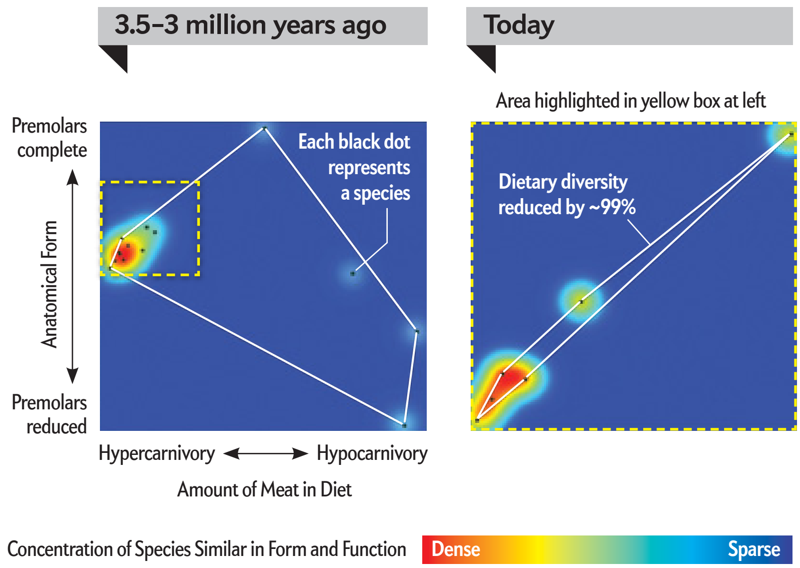
Nevertheless, to determine whether human activity was responsible for the decline of these carnivores, it would help to know how important meat was to early *Homo*. Archaeologists have long debated this question. Some think meat and hunting were critically important; others hold that meat was a marginal component of the diet at best, with the hominins merely scavenging a few scraps that carnivores rejected. But they generally agree that *Homo* did begin to obtain more protein from animals, perhaps including fish and shellfish, between two million and 1.5 million years ago in the Early Pleistocene period.

Anthropologist Henry Bunn of the University of Wisconsin–Madison envisions the transition to a meatier diet unfolding in three steps, the timings of which dovetail nicely with the idea that competition with early hominins drove many big carnivores to extinction. First, hominins occasionally butchered bones using primitive stone tools or naturally flaked blades. At this stage, which Bunn puts at around 2.6 million to 2.5 million years ago, based on the available archaeological evidence, they had only a slight ability to obtain meat. The second stage involved more habitual butchery, along with the skills to break bones to get at the marrow inside and to transport meat-rich parts of carcasses to a home base or similar. Bunn estimates that hominins reached this stage around 2.3 million to 1.9 million years ago and that by this point they could obtain meat on a regular basis through scavenging and possibly making their own kills. In the third stage, hominins butchered animal remains extensively and had access to intact carcasses because they were better at appropriating car-

FINDINGS

A Shadow of Their Former Selves

Studies of African mammalian carnivore fossils from the past seven million years show that the large members of this group have declined dramatically both in terms of the number of species and in a feature called functional richness—diversity in what the animals eat. Once upon a time the community of large carnivores ranged from those adapted to eating mostly plant foods (hypocarnivores) to those built for subsisting mainly on meat (hypercarnivores); today a few hypercarnivores are all that remain. The timing of the decline coincides with the rise of *Homo erectus,* the first human ancestor to incorporate significant amounts of meat in its diet, suggesting that competition with humans for access to prey drove many big carnivores to extinction.



Evidence of Lost Diversity

The reduced diversity of carnivore types is revealed by plotting the development of the premolar teeth (an indicator of how an animal obtains food and how hard that food is to chew) against the proportion of meat in the diet (inferred from features of the jaws and teeth) for each species (*black dot*) present during a given time span and by comparing the areas of the polygons encompassing all the species plotted in each time frame. The exercise shows the large carnivores have lost nearly 99 percent of the dietary diversity they had at their peak between 3.5 million and three million years ago, before the dawn of *Homo.*

FROM "TEMPORAL CHANGE IN FUNCTIONAL RICHNESS AND EVENNESS IN THE EASTERN AFRICAN PLIO-PLEISTOCENE CARNIVORAN GUILD," BY LARS WERDELIN AND MARGARET E. LEWIS, IN *PLOS ONE,* VOL. 8, NO. 3; MARCH 6, 2013 nivore kills or possibly because they were routinely hunting the animals themselves. Bunn dates this last stage to between 1.8 million and 1.6 million years ago.

Thus, although they lacked the lethal teeth and claws and the sheer physical strength of the sabertooth cats and other large carnivores, hominins were able to level the playing field through their rapidly evolving intelligence and social cooperation—there is strength in numbers even if brawn is lacking. And in lean times, hominins would have had a distinct advantage over carnivores, especially hypercarnivores such as the sabertooths, because, being omnivorous, they had a much larger array of foods they could fall back on when their top choices were unavailable. During the worst times of the year, then, the hominin competitive edge would have been the greatest. (That the remaining large carnivores are all hypercarnivores reflects the fact that there were many more kinds of hypercarnivores to start with than omnivores or hypocarnivores.)

The entry of early *Homo* into the carnivore niche in Africa could have triggered an even more dramatic cascade of ecological disruption than the one that occurred at Yellowstone.

FOOD FOR THOUGHT

LIKE ANY NASCENT HYPOTHESIS, this one comes with a series of problems that need resolution. The most significant of these issues concerns the timing of the events described here, both in terms of when the carnivores began going downhill and when humans started to pose a competitive threat to them. We need a clearer picture of what happened and when to draw firm conclusions about cause and effect. In addition, scientists do not know whether hominins were sufficiently numerous and competitive to cause such massive change to the carnivore community.

Pinpointing when the carnivore decline began requires either the discovery of additional fossils from the 2.5-million- to two-million-year time interval or more refined techniques for analyzing the fossils we already have. I am currently working on developing such techniques. What I can definitely say at this point is that the onset of change in the carnivores had occurred by 1.8 million years ago and that the most refined analysis at present suggests that it occurred shortly before two million years ago. Whether this can be accurately matched up with events in hominin evolution, however, is not yet clear. Although Bunn's timetable is fully compatible with the scenario I have presented, it has not gone unchallenged. Other scholars suspect the first two stages occurred considerably later than he proposes.

Resolution of the issue of hominin numbers and competitive ability may never come. These aspects of early hominins are currently mostly a matter of opinion. Undoubtedly, population density was low, but how low is unknown. It may be possible to generate a series of simulations of both factors to see whether the hypothesis is viable given reasonable values for either or both. But hard evidence of how many hominins were around and how successful they were in getting hold of prey that would have otherwise ended up in a sabertooth's belly may always elude science's grasp. The absence of these data does not demonstrate that my hypothesis is false, however.

I hope that researchers skeptical of my hypothesis will come up with some ingenious ways of testing it. To that end, another aspect of this idea bears mention. Attempts to explain ecosystem change typically provide a bottom-up perspective, looking at how climate factors affect plants and how changes in those organisms affect the rest of the food chain up to the top predators. My hypothesis about eastern Africa's large carnivores provides a top-down view, considering how change in the top predators could affect the primary producers at the bottom of the food chain, such as grasses and trees.

The reintroduction of wolves to Yellowstone National Park and their effect on the herbivores living there, and by extension on the vegetation of the park, provide a stunning example of the impact of change among top predators. As the wolves became more plentiful, the elk they preyed on diminished in numbers. This in turn led to less feeding pressure on the plants and to lusher vegetation in those places where the herbivores were previously particularly common [see "Lessons from the Wolf," by Jim Robbins; SCIENTIFIC AMERICAN, June 2004].

The entry of early *Homo* into the carnivore niche in Africa could have triggered an even more dramatic cascade of ecological disruption than the one that occurred at Yellowstone. Whereas wolves were once a natural part of the Yellowstone ecosystem, meaning that the other species there retained at least some adaptations to their presence, early *Homo* had no such precedent. One would expect the introduction of such a new predator to have even greater consequences for the ecosystem than the reintroduction of one that had been there originally. Perhaps, then, the smoking gun in the case of the disappearing carnivores will turn up not among the remains of our hominin ancestors or the large carnivores themselves but among the remnants of herbivores and plants whose world was upended when *Homo* developed a taste for meat. SA

MORE TO EXPLORE

Patterns of Change in the Plio-Pleistocene Carnivorans of Eastern Africa: Implications for Hominin Evolution. Margaret E. Lewis and Lars Werdelin in *Hominin Environments in the East African Pliocene: An Assessment of the Faunal Evidence.* Springer Verlag, 2007.

Temporal Change in Functional Richness and Evenness in the Eastern African Plio-Pleistocene Carnivoran Guild. Lars Werdelin and Margaret E. Lewis in *PLOS ONE,* Vol. 8, No. 3, pages 1–11; March 2013.

SCIENTIFIC AMERICAN ONLINE
For a graphic showing why climate change does not explain the large carnivore decline, visit **ScientificAmerican.com/nov2013/carnivores**

ASTRONOMY

WORLDS WITH TWO SUNS

Astronomers are discovering distant planets that

Illustrations by Ron Miller

orbit two-star systems, uncovering bizarre and wondrous worlds unlike anything in our solar system

By William F. Welsh and Laurance R. Doyle

William F. Welsh is a professor of astronomy at San Diego State University.

Laurance R. Doyle is an astrophysicist at the SETI Institute in Mountain View, Calif.

As beautiful as sunsets are on Earth, imagine a double sunset with stars of different colors, casting moving shadows of orange and red.

For years the two of us wondered if paired, or "binary," stars could support planets. Could worlds like the fictional Tatooine from *Star Wars,* where the sky is lit with the glow of two different suns, really exist?

Astronomers had reason to think such systems might exist, yet some theorists disagreed. The environment around a pair of stars, they argued, would be too chaotic for planets to form. Unlike a body circling a single star, a planet orbiting a pair of stars would have to contend with two gravitational fields. And because the stars themselves orbit each other, the strength of the gravitational forces would constantly change. Even if a planet could form in such a dynamic environment, its long-term stability would not be assured—the planet could wind up being ejected into deep space or crashing into one of the stars. Observations of binary star systems had shown some indirect evidence for these "circumbinary" planets, but direct evidence remained elusive.

Over two decades of effort by William Borucki and his collaborators to get an exoplanet-hunting spacecraft launched finally came to fruition in March 2009. NASA's Kepler Mission has since proved to be spectacularly successful, quickly revealing hundreds, then thousands, of planet candidates via the transit method, which searches for the mini eclipse that occurs when a planet orbits in front of the star, blocking some of its light. But after two years, no circumbinary planets had been detected. The frustrating lack of evidence began to take its toll. In a weekly Kepler telephone conference in the spring of 2011, one of us offered an attempt at black humor: "Maybe we should write a paper on why they don't exist." Silence followed.

Our fears were misplaced. Within six months of that conversation we had a press conference to announce the discovery of the first *transiting* circumbinary planet. This planet was called Kepler-16b. Within months the Kepler Eclipsing Binary Working Group discovered two more circumbinary planets (Kepler-34b and Kepler-35b), showing that while exotic, such systems are not rare. A new class of planet system had been established. The current tally of Kepler circumbinary planets is seven, and that number could double in a short time. In fact, calculations suggest that tens of millions likely exist in the Milky Way.

SEARCH STRATEGIES

THE QUEST for circumbinary planets began in the 1980s, even before astronomers found the first evidence of any "exoplanets" outside our solar system [see "Searching for Shadows of Other

IN BRIEF

Binary stars are very common, and so astronomers wondered if "circumbinary planets"—planets that orbit around two stars—could exist.

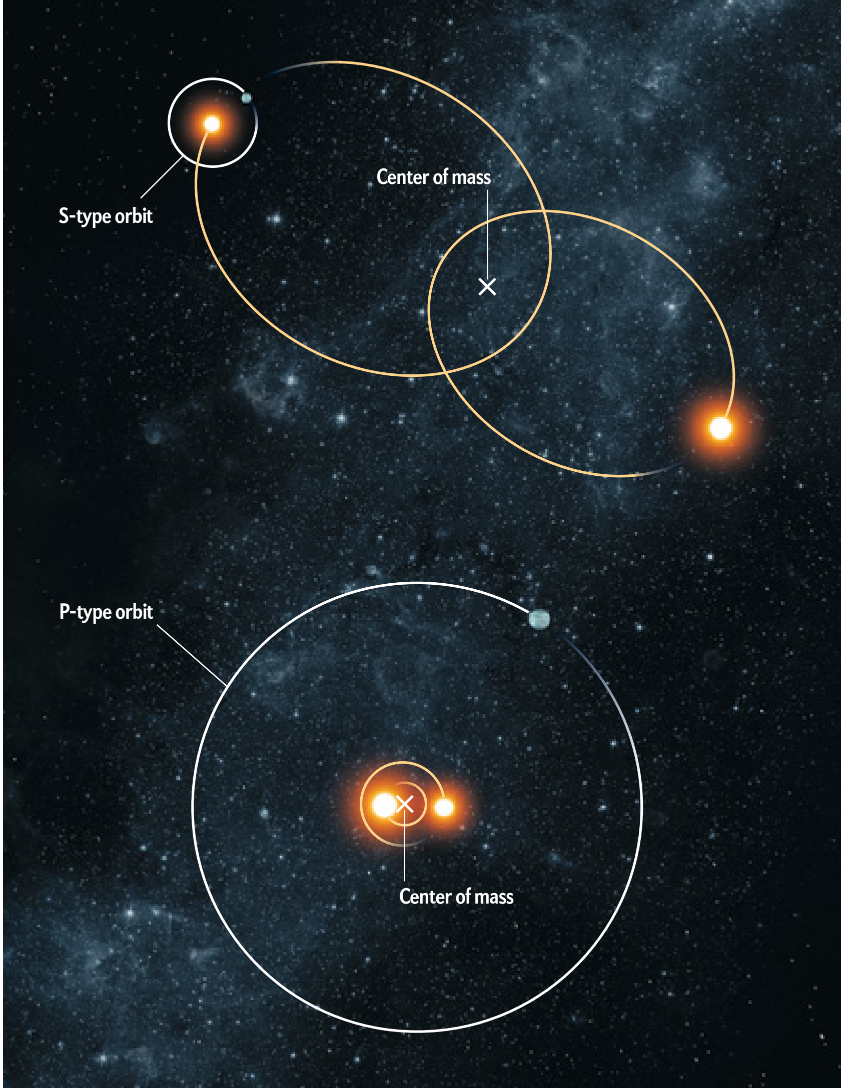
Some feared that the environment around a binary star might prove to be too chaotic to allow for planet formation.

But recent discoveries show that not only do circumbinary planets exist, they can even reside in a system's habitable zone, where liquid water is possible.

ASTROTAXONOMY

Two Types of Binary Planets

Binary star systems come in many different forms. Some binary stars make huge, looping orbits around their common center of mass, taking hundreds of years to complete a single orbit. These stars tend to act almost as if isolated; an "S-type" planet can orbit one star in the pair without being bothered by the other. In contrast, stars close together can orbit each other in weeks or days. For years it was an open question whether "P-type" planets could survive the chaotic gravitational environment and orbit around the pair of stars.



Earths," by Laurance R. Doyle, Hans-Jörg Deeg and Timothy M. Brown; Scientific American, September 2000, and references therein]. Although transits can be much more complicated in a binary system, hopes for discovering such a system were fueled by a simple expectation: if a planet did orbit an eclipsing binary star system, we would expect it to travel in the same orbital plane as the stars themselves. In other words, if from our perspective on Earth the stars eclipsed each other, then the planet would be much more likely to eclipse one or both stars. This assumed that the planet and the stars had co-planar orbits, a reasonable hypothesis—and one that could be tested.

Eclipsing binary stars are in many ways the foundation on which stellar astrophysics is built. Their special orientation along our line of sight means that the stars pass in front of each other once per orbit, blocking some of the light. By precisely modeling how the light dims during the eclipses, we can learn the sizes and shapes of the stars and the geometry of their orbits. Coupled with other measurements, we can measure the stars' radii and masses. Eclipsing binary stars thus provide a fundamental calibration of stellar masses and radii, which in turn are used to estimate the stellar properties for noneclipsing and single stars.

If the two stars in a binary system are very far apart, with an orbital period of, say, hundreds of years, the stars hardly affect each other, and they act almost as if in isolation. Planets may orbit either one of the stars and in general will not be much influenced by the presence of the other star. These are known as circumstellar, or S-type, planets, and dozens of such planets have been discovered in the past decade.

Things get more interesting when stars are so close together that they take only weeks, or even days, to orbit each other. For a planet in such a binary to have a stable orbit, it would have to orbit both stars, not just one. Numerical calculations show that the planet's orbital separation from the stars has to be larger than a minimum critical distance; too close and the rotating binary system would destabilize the planet's orbit, either swallowing it up or ejecting it out into the galaxy. The minimum stable separation is roughly two to three times the size of the stars' separation. These kinds of planets are known as circumbinary, or P-type, planets. While planets around single stars and around individual stars in widely separated binaries are common, we wondered if nature could make planetary systems in the circumbinary configuration, where the planet orbits both stars.

In a simple one-star, one-planet system, transits will occur with a metronomic periodicity that greatly assists in their detection. Add another star, though, and the three-body system will start to display all manner of complicated effects. The complexity arises because the stars are quickly moving—in contrast to the single-star system where the star is effectively stationary. In fact,

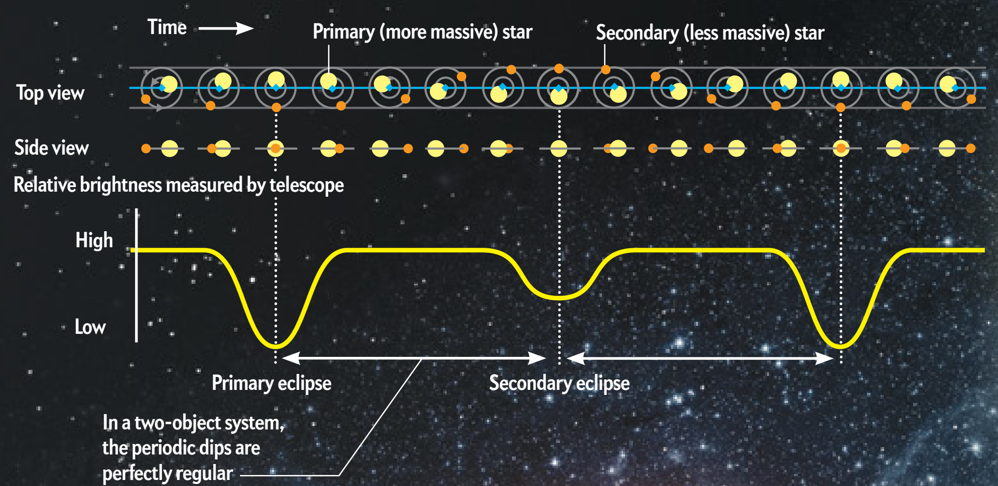
How to Find Planets around Multistar Systems

Binary stars are uniquely revealing astronomical objects. If, from our point of view, the stars eclipse each other during their orbits, we can learn much about each star by measuring how light dims during the eclipse. These eclipses can also be exploited to find planets that orbit around a binary star system. But finding these planets is not easy—the three-object systems can behave in complex ways. The illustrations here are idealized versions of the effects that astronomers look for. *—The Editors*

What Binary Stars Look Like

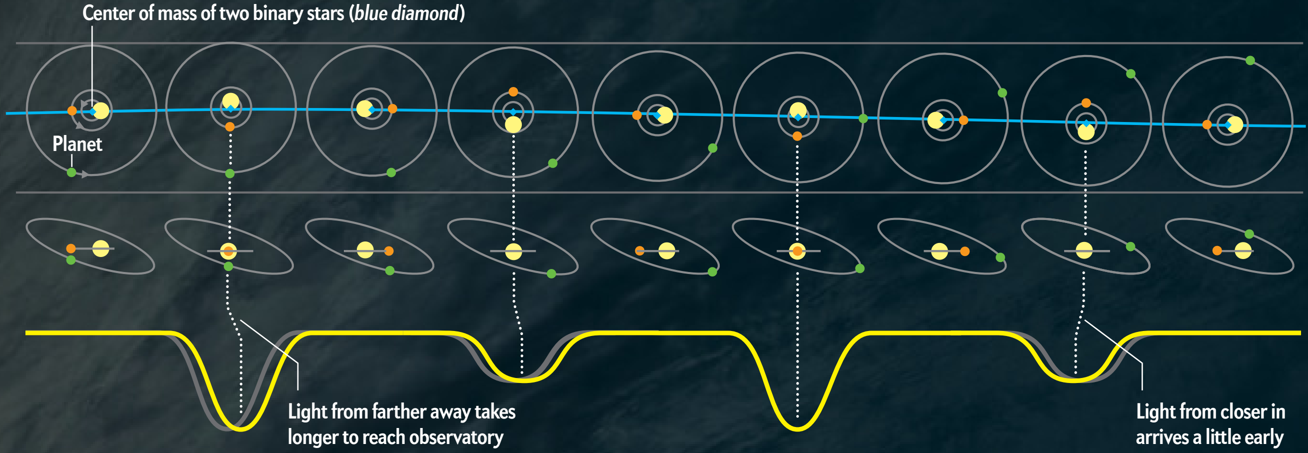
Schematics are not to scale

In an eclipsing binary star system, each star will briefly block the light of the other, creating periodic dips in brightness



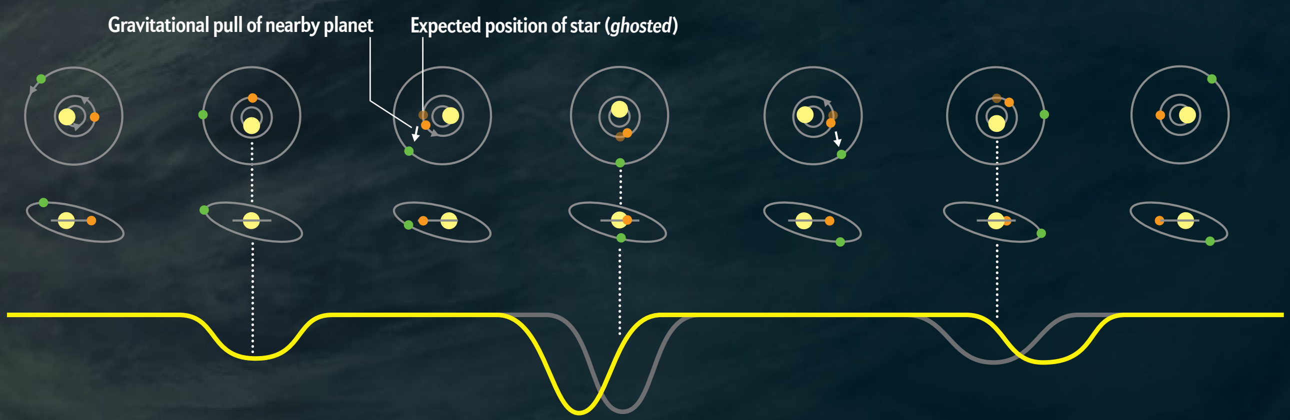
The Light-Travel Time Effect

In a three-body system, the center of mass of the two binary stars orbits around the center of mass of the three-body system. As a consequence, at times the stars will be farther away from Earth, at other times closer to us. Extra distance means it takes longer for light from the binary eclipse to reach our telescopes, slightly delaying the observed eclipse timing. A shorter distance produces eclipses that are early.



The Dynamical Effect

Planets can also alter the dynamics of a two-star system. If the planet's orbital radius is relatively small, it will affect one (or both) of the stars as they orbit. Moreover, if one of the stars is less massive than the other, its orbit will pass closer to the planet, amplifying the effect. The close passes can modify the two-body orbits in complex ways. In this example, the planet's tug on the secondary star causes it to arrive at the primary eclipse early and at the secondary eclipse late.



Planetary Transits across Binary Stars

If a planet passes in front of a star, it can block a little of the star's light. In a circumbinary system, the background stars are moving. As a consequence, sometimes the planet passes in front of the star early or sometimes late. In addition, if the planet and star are moving in the same direction, the transit will take longer; in the opposite direction, it will be shorter. This effect creates delays of days or more.

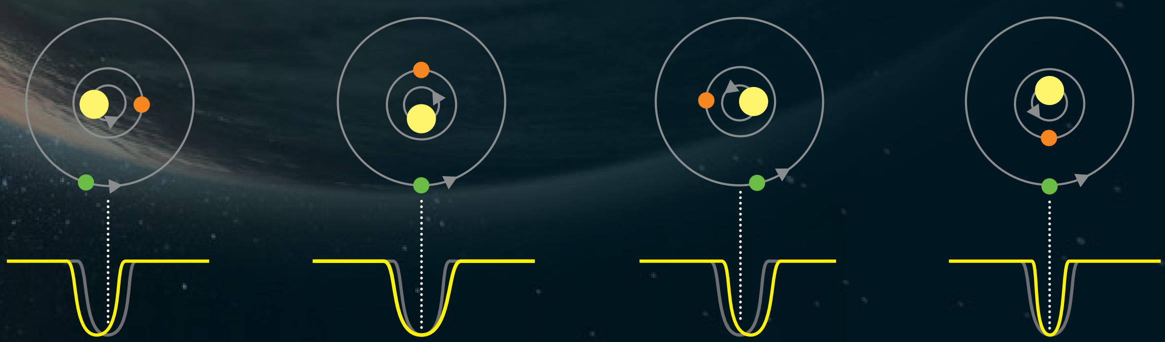


Illustration by Ron Miller, Graphic by Jen Christiansen because the two stars are closer to each other than they are to the planet, they must orbit each other faster than the planet will orbit them—a manifestation of Johannes Kepler's famous laws of planetary motion. Thus, the planet will be transiting a quickly moving target, and sometimes it will cross the star early and sometimes late [*see box on page 44*]. While precisely predictable (if the masses and orbits are known), the transits will not be periodic. In addition, the duration of the transit will change depending on the relative motion of the planet to the star being crossed—if they are moving in the same direction, the transit will be longer in duration, but when the star is on the other half of its orbit and moving the other direction, the transit will be shorter. These variations make detecting circumbinary planets difficult, but they also offer an important benefit: once the binary star's orbit is deciphered, the pattern of changing transit times and durations can be used to unequivocally confirm the presence of an orbiting circumbinary body. No other astronomical phenomenon exhibits such a pattern. This is a unique characteristic of a circumbinary object—a smoking gun signature.

THE FIRST DETECTION

UNTIL TECHNICAL PROBLEMS SIDELINED IT earlier this year, Kepler had kept its eye trained on a single patch of sky, looking for the characteristic dimming caused by planets crossing in front of host stars. In its quest for planets, Kepler also discovered more than 2,000 new eclipsing binary star systems. Several exotic systems were discovered, including the first known eclipsing triple-star systems.

In 2011 one of us (Doyle), along with associate Robert Slawson, working with him at the SETI Institute in Mountain View, Calif., noticed extra eclipse events in the binary stars known as KIC 12644769. The two stars eclipsed each other every 41 days, but there were three other unexplained eclipse events. The first two occurred 230 days apart. The next occurred 221 days later—nine days earlier than expected. This was just the kind of signature one would get from a circumbinary planet.

These transits thus provided evidence of a third body orbiting the binary. But it could have been just a dim, small star grazing part of the large star—and as Kepler was showing us, such triple-star eclipsing systems are not exceptionally rare. The slight dimming indicated that the object could have a small radius, but starlike objects such as brown dwarf stars are also small, so we could not say for sure if the object was a planet. We had to measure its mass.

In a three-body system, an unseen companion to a binary can make its presence known in two main ways. Imagine two stars eclipsing each other, with a relatively large planet circling the pair farther away. The binary stars orbit each other, but in addition, the center of mass of the pair is orbiting the center of mass of the three-body system [*see box on page 45*]. As a consequence, sometimes the binary stars will be displaced a little bit closer to Earth; at other times, they will be farther away. When they are farther away, light from the stars will take longer to reach us and the eclipses will occur slightly late. When the stars are closer to us, the eclipses will be early. The larger the mass of the third body, the larger the change. Thus, this cyclic light-travel time effect allows one to infer the presence and estimate the mass of any unseen object. Also, the farther away the third body is from the binary, the greater the effect because the added distance will act as a lever, but the farther away, the longer the cycle time. In the case of our candidate circumbinary planet, there was no detectable cyclic change in the eclipse timing on the order of 230 days, implying that the hidden body had a low mass. But how low?

The other way for a third body to affect the binary is through direct gravitational interaction, called the dynamical effect. This method dominates the light-travel time effect for closer objects. The unseen companion slightly alters the orbits of the binary stars, and these changes can be picked up through variations in the occurrence times of the eclipses. Because the smaller star comes closer to the third body, its orbit will be perturbed more. Unlike the light-travel time effect, the dynamical effect alters the times of the eclipses in complex ways.

One of our colleagues on the Kepler Science Team, Daniel C. Fabrycky, now at the University of Chicago, noted that a stellar-mass object would strongly affect the eclipse times, whereas a planet would produce a much more subtle—but potentially measurable—signature. And for this system, the dynamical effects should be very much stronger than the light-travel time effect. We looked for and subsequently found the changes in eclipse timing, revealing that the tug on the stars was not anywhere near what a stellar-mass companion would produce.

The grand finale of the investigation was provided when Joshua A. Carter of the Harvard-Smithsonian Center for Astrophysics was able to create a sophisticated computer model of the system. It matched the complete data set perfectly for a planet with a mass similar to Saturn's. The excellent match between the observations and the modeling proved the existence of the planet and provided exquisitely precise values for the radii, masses and orbital characteristics of the system.

This planet was designated Kepler-16b and was the first *transiting* circumbinary planet discovered. The combination of the transits and the clear dynamical effects made this detection unambiguous. Because the binary stars would appear as sun-size disks as seen from this planet, Kepler-16b soon acquired the nickname "Tatooine" from the fictional planet in *Star Wars* and its iconic image of a double sunset. Science fiction had become science fact.

A NEW CLASS OF PLANET

KEPLER-16B APPEARED, at first, to be a very strange planet. Its orbit is uncomfortably close to its host stars, being only 9 percent farther out than the minimum critical distance needed for orbital stability. And because this was the only transiting circumbinary planet at the time, we asked ourselves: Is Kepler-16b just a fluke?

Fortunately, the answer came quickly. Working with Jerome A. Orosz of San Diego State University, we had already been searching for circumbinary planets that do *not* transit their stars. These should be far more common than transiting cases, since the special alignment of the planet's orbit to create a transit is not required. As mentioned, small variations in eclipse timings should reveal such planets. We had been pursuing this line of research for a few months and had identified a few candidate systems. Then, on a Tuesday afternoon in August 2012, one of us (Welsh) noticed transits in one of the binary star systems. Within hours Fabrycky had created a computer model that reproduced the variable transit times and durations, confirming the transiting object as a planet. We had discovered Kepler-34b. Working feverishly, the very next day Orosz found transits in another eclipsing binary star system, and it, too, harbored a planet—Kepler-35b.

Over the next few months Orosz would go on to discover

Kepler-38b, showing that smaller, Neptune-mass circumbinary planets also exist, and then the Kepler-47 planetary system with at least two planets, showing that binary stars can harbor multiple planets. The most recent circumbinary planet discovered, Kepler-64b (also known as PH1) was simultaneously and independently discovered by Johns Hopkins University graduate student Veselin Kostov and by amateur astronomers working as part of the Planet Hunters project. It is part of a quadruple-star system, further extending the diversity of places where planets can form.

The seven circumbinary planets found so far tell us that these objects are not extremely rare but rather that we have uncovered a whole new class of planetary system. For every transiting planetary system detected, geometry tells us that there are roughly five to 10 planets that we do not see because they do not have the correct orientation to pass in front of the binary stars as seen from our vantage point. Given that seven planets were found out of roughly 1,000 eclipsing binaries searched, we can conservatively estimate that the galaxy is home to tens of millions of such circumbinary planetary systems.

Even though we do not understand why these planets seem to prefer such precarious orbits, we can infer something deep: planet formation is vigorous and robust.

All the Kepler transiting circumbinary planets to date are gas-giant planets, worlds without the rocky crust that would allow an astronaut to stand on its surface and marvel at the double sunsets. The search continues for smaller rocky planets, although Earth-size circumbinary planets are going to be extremely difficult to detect.

But even with such a small sample of planets, a number of interesting questions arise. For instance, half of all the Kepler eclipsing binaries have an orbital period of less than 2.7 days, so we expected that half of the binaries with planets would also have periods less than 2.7 days. But none of them do; the shortest orbital period is 7.4 days. Why? We speculate that it might be related to the process that brought the stars so close together in the first place.

In addition, the planets tend to orbit their stars very closely. If they were in much closer, the planets' orbits would be unstable. What, then, causes them to live so dangerously? Understanding why the circumbinary planets orbit so close to their critical instability radius will help us improve theories about how planets form and how their orbits evolve over time.

Even though we do not know why these planets seem to prefer such precarious orbits, we can nonetheless infer something deep: the discovery that planets can live so near a chaotic environment is telling us that planet formation is vigorous and robust.

A DYNAMIC HABITABLE ZONE

THE TENDENCY of the Kepler circumbinary planets to lie near the critical stability radius has an interesting consequence. For the Kepler sample of stars, the critical radius is generally close to the habitable zone—the region around a star (or in this case, around two stars) where the energy from that star makes the planet's temperature just right for water to persist in the liquid state. Too close to the star, and the planet's water boils; too far away, and the water freezes. And water is a prerequisite for life as we know it.

For a single star, the habitable zone is a spherical-shell region around that star. In a binary system, each star has its own habitable zone, which merge into a distorted spheroid if the stars are close enough together, as is the case for the Kepler circumbinary planets. As the stars orbit each other, the combined habitable zone also revolves with the stars. Because the stars orbit faster than the planet does, the habitable zone swings around more quickly than the planet orbits.

Unlike Earth, which is in a near-circular orbit around the sun, the distance a circumbinary planet has to each of its host stars can change radically over the course of the planet's orbital year. Thus, planetary seasons could wax and wane in only a few weeks as the stars whirl about each other. These climate changes could be large and only quasi regular—"It would be a wild ride," Orosz notes.

Two of the seven known transiting circumbinary planets are in their system's habitable zone, a remarkably high percentage. Although being in the habitable zone does not guarantee conditions suitable for life—Earth's moon is in the sun's habitable zone and yet is as desolate as can be imagined because its small mass is too feeble to retain an atmosphere, for example—the high fraction of circumbinary planets in their habitable zones does cause one to pause and wonder. With its severe and rapidly changing seasons, what would life, and indeed a civilization, be like on a circumbinary world? SA

MORE TO EXPLORE

Kepler-16: A Transiting Circumbinary Planet. Laurance R. Doyle et al. in *Science*, Vol. 333, pages 1602–1606; September 16, 2011.

Transiting Circumbinary Planets Kepler-34 b and Kepler-35 b. William F. Welsh et al. in *Nature*, Vol. 481, pages 475–479; January 26, 2012.

Kepler-47: A Transiting Circumbinary Multiplanet System. Jerome A. Orosz et al. in *Science*, Vol. 337, pages 1511–1514; September 21, 2012.

The Kepler Mission: **http://kepler.nasa.gov**

The Planet Hunters: **www.planethunters.org**

SCIENTIFIC AMERICAN ONLINE
Watch animations of the Kepler-16 and other circumbinary systems at **ScientificAmerican.com/nov2013/planets**


THE TRAGEDY OF HAMLET
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MIND

Why the Brain Prefers Paper

E-readers and tablets are becoming more popular as such technologies improve, but reading on paper still has its advantages

By Ferris Jabr

IN BRIEF

Studies in the past two decades indicate that people often understand and remember text on paper better than on a screen. Screens may inhibit comprehension by preventing people from intuitively navigating and mentally mapping long texts.

In general, screens are also more cognitively and physically taxing than paper. Scrolling demands constant conscious effort, and LCD screens on tablets and laptops can strain the eyes and cause headaches by shining light directly on people's faces.

Preliminary research suggests that even so-called digital natives are more likely to recall the gist of a story when they read it on paper because enhanced e-books and e-readers themselves are too distracting. Paper's greatest strength may be its simplicity.

One of the most provocative viral YouTube videos in the past two years begins mundanely enough: a one-year-old girl plays with an iPad, sweeping her fingers across its touch screen and shuffling groups of icons. In following scenes, she appears to pinch, swipe and prod the pages of paper magazines as though they, too, are screens. Melodramatically, the video replays these gestures in close-up.

For the girl's father, the video—*A Magazine Is an iPad That Does Not Work*—is evidence of a generational transition. In an accompanying description, he writes, "Magazines are now useless and impossible to understand, for digital natives"—that is, for people who have been interacting with digital technologies from a very early age, surrounded not only by paper books and magazines but also by smartphones, Kindles and iPads.

Whether or not his daughter truly expected the magazines to behave like an iPad, the video brings into focus a question that is relevant to far more than the youngest among us: How exactly does the technology we use to read change the way we read?

Since at least the 1980s researchers in psychology, computer engineering, and library and information science have published more than 100 studies exploring differences in how people read on paper and on screens. Before 1992 most experiments concluded that people read stories and articles on screens more slowly and remember less about them. As the resolution of screens on all kinds of devices sharpened, however, a more mixed set of findings began to emerge. Recent surveys suggest that although most people still prefer paper—especially when they need to concentrate for a long time—attitudes are changing as tablets and e-reading technology improve and as reading digital texts for facts and fun becomes more common. In the U.S., e-books currently make up more than 20 percent of all books sold to the general public.

Despite all the increasingly user-friendly and popular technology, most studies published since the early 1990s confirm earlier conclusions: paper still has advantages over screens as a reading medium. Together laboratory experiments, polls and consumer reports indicate that digital devices prevent people from efficiently navigating long texts, which may subtly inhibit reading comprehension. Compared with paper, screens may also drain more of our mental resources while we are reading and make it a little harder to remember what we read when we are done. Whether they realize it or not, people often approach computers and tablets with a state of mind less conducive to learning than the one they bring to paper. And e-readers fail to re-create certain tactile experiences of reading on paper, the absence of which some find unsettling.

"There is physicality in reading," says cognitive scientist Maryanne Wolf of Tufts University, "maybe even more than we want to think about as we lurch into digital reading—as we move forward perhaps with too little reflection. I would like to preserve the absolute best of older forms but know when to use the new."

TEXTUAL LANDSCAPES

UNDERSTANDING HOW READING on paper differs from reading on screens requires some explanation of how the human brain interprets written language. Although letters and words are symbols representing sounds and ideas, the brain also regards them as physical objects. As Wolf explains in her 2007 book *Proust and the Squid,* we are not born with brain circuits dedicated to reading, because we did not invent writing until relatively recently in our evolutionary history, around the fourth millennium B.C. So in childhood, the brain improvises a brand-new circuit for reading by weaving together various ribbons of neural tissue devoted to other abilities, such as speaking, motor coordination and vision.

Some of these repurposed brain regions specialize in object recognition: they help us instantly distinguish an apple from an orange, for example, based on their distinct features, yet classify both as fruit. Similarly, when we learn to read and write, we begin

PRECEDING PAGES: KYLE BEAN

to recognize letters by their particular arrangements of lines, curves and hollow spaces—a tactile learning process that requires both our eyes and hands. In recent research by Karin James of Indiana University Bloomington, the reading circuits of five-year-old children crackled with activity when they practiced writing letters by hand but not when they typed letters on a keyboard. And when people read cursive writing or intricate characters such as Japanese *kanji,* the brain literally goes through the motions of writing, even if the hands are empty.

Beyond treating individual letters as physical objects, the human brain may also perceive a text in its entirety as a kind of physical landscape. When we read, we construct a mental representation of the text. The exact nature of such representations remains unclear, but some researchers think they are similar to the mental maps we create of terrain—such as mountains and trails—and of indoor physical spaces, such as apartments and offices. Both anecdotally and in published studies, people report that when trying to locate a particular passage in a book, they often remember where in the text it appeared. Much as we might recall that we passed the red farmhouse near the start of a hiking trail before we started climbing uphill through the forest, we remember that we read about Mr. Darcy rebuffing Elizabeth Bennett at a dance on the bottom left corner of the left-hand page in one of the earlier chapters of Jane Austen's *Pride and Prejudice.*

The human brain may perceive a text in its entirety as a kind of physical landscape. When we read, we construct a mental representation of the text that is likely similar to the mental maps we create of terrain and indoor spaces.

In most cases, paper books have more obvious topography than on-screen text. An open paper book presents a reader with two clearly defined domains—the left- and right-hand pages—and a total of eight corners with which to orient oneself. You can focus on a single page of a paper book without losing awareness of the whole text. You can even feel the thickness of the pages you have read in one hand and the pages you have yet to read in the other. Turning the pages of a paper book is like leaving one footprint after another on a trail—there is a rhythm to it and a visible record of how far one has traveled. All these features not only make the text in a paper book easily navigable, they also make it easier to form a coherent mental map of that text.

In contrast, most digital devices interfere with intuitive navigation of a text and inhibit people from mapping the journey in their mind. A reader of digital text might scroll through a seamless stream of words, tap forward one page at a time or use the search function to immediately locate a particular phrase—but it is difficult to see any one passage in the context of the entire text. As an analogy, imagine if Google Maps allowed people to navigate street by individual street, as well as to teleport to any specific address, but prevented them from zooming out to see a neighborhood, state or country. Likewise, glancing at a progress bar gives a far more vague sense of place than feeling the weight of read and unread pages. And although e-readers and tablets replicate pagination, the displayed pages are ephemeral. Once read, those pages vanish. Instead of hiking the trail yourself, you watch the trees, rocks and moss pass by in flashes, with no tangible trace of what came before and no easy way to see what lies ahead.

"The implicit feel of where you are in a physical book turns out to be more important than we realized," says Abigail J. Sellen of Microsoft Research Cambridge in England, who co-authored the 2001 book *The Myth of the Paperless Office.* "Only when you get an e-book do you start to miss it. I don't think e-book manufacturers have thought enough about how you might visualize where you are in a book."

EXHAUSTIVE READING

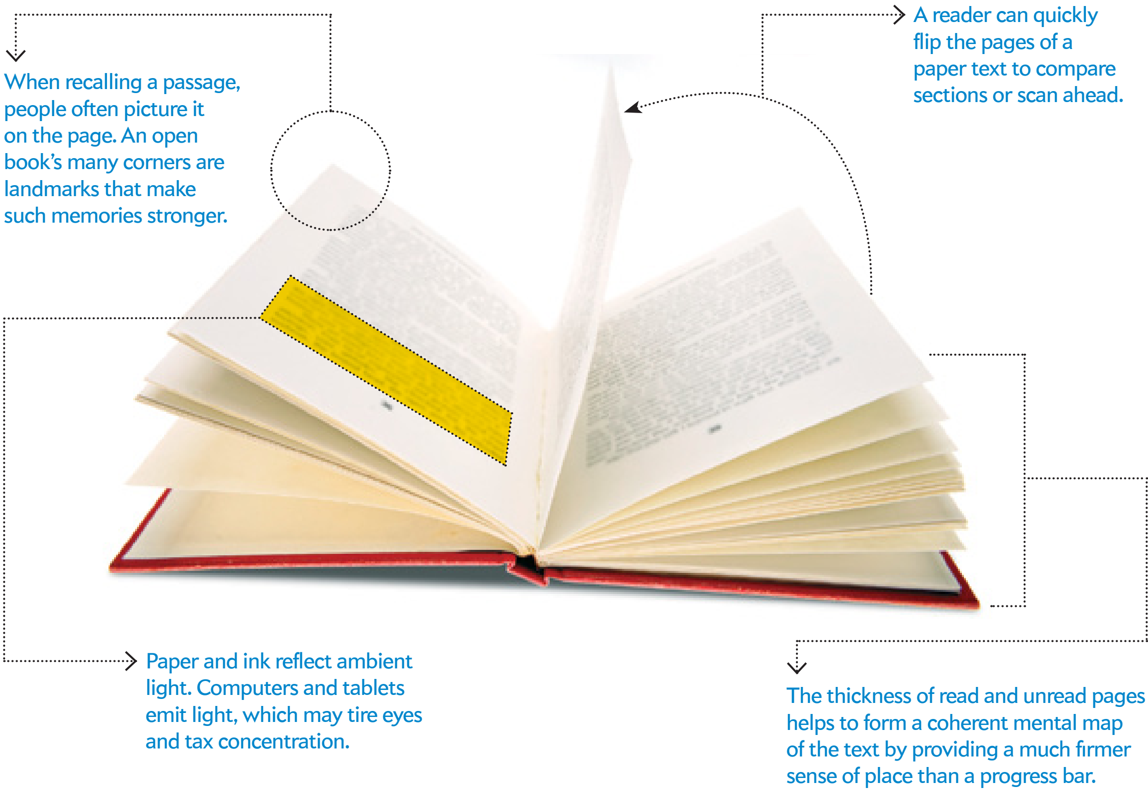
AT LEAST A FEW STUDIES suggest that screens sometimes impair comprehension precisely because they distort people's sense of place in a text. In a January 2013 study by Anne Mangen of the University of Stavanger in Norway and her colleagues, 72 10th grade students studied one narrative and one expository text. Half the students read on paper, and half read PDF files on computers. Afterward, students completed reading comprehension tests, during which they had access to the texts. Students who read the texts on computers performed a little worse, most likely because they had to scroll or click through the PDFs one section at a time, whereas students reading on paper held the entire texts in their hands and quickly switched between different pages. "The ease with which you can find out the beginning, end, and everything in between and the constant connection to your path, your progress in the text, might be some way of making it less taxing cognitively," Mangen says. "You have more free capacity for comprehension."

Other researchers agree that screen-based reading can dull comprehension because it is more mentally taxing and even physically tiring than reading on paper. E-ink reflects ambient light just like the ink on a paper book, but computer screens, smartphones and tablets shine light directly on people's faces. Today's LCDs are certainly gentler on eyes than their predecessor, cathode-ray tube (CRT) screens, but prolonged reading on glossy, self-illuminated screens can cause eyestrain, headaches and blurred vision. In an experiment by Erik Wästlund, then at Karlstad University in Sweden, people who took a reading comprehension test on a computer scored lower and reported higher levels of stress and tiredness than people who completed it on paper.

In a related set of Wästlund's experiments, 82 volunteers completed the same reading comprehension test on computers, either as a paginated document or as a continuous piece of text. Afterward, researchers assessed the students' attention and working memory—a collection of mental talents allowing people to temporarily store and manipulate information in their mind. Volunteers had to quickly close a series of pop-up windows, for example, or remember digits that flashed on a screen. Like many cognitive abilities, working memory is a finite resource that diminishes with exertion.

Weighing Paper against Pixel

In many studies people understand and remember what they read on paper better than what they read on screens. Researchers think the physicality of paper explains this discrepancy.



ISTOCKPHOTO

Although people in both groups performed equally well, those who had to scroll through the unbroken text did worse on the attention and working memory tests. Wästlund thinks that scrolling—which requires readers to consciously focus on both the text and how they are moving it—drains more mental resources than turning or clicking a page, which are simpler and more automatic gestures. The more attention is diverted to moving through a text, the less is available for understanding it. A 2004 study conducted at the University of Central Florida reached similar conclusions.

An emerging collection of studies emphasizes that in addition to screens possibly leeching more attention than paper, people do not always bring as much mental effort to screens in the first place. Based on a detailed 2005 survey of 113 people in northern California, Ziming Liu of San Jose State University concluded that those reading on screens take a lot of shortcuts—they spend more time browsing, scanning and hunting for keywords compared with people reading on paper and are more likely to read a document once and only once.

When reading on screens, individuals seem less inclined to engage in what psychologists call metacognitive learning regulation—setting specific goals, rereading difficult sections and checking how much one has understood along the way. In a 2011 experiment at the Technion–Israel Institute of Technology, college students took multiple-choice exams about expository texts either on computers or on paper. Researchers limited half the volunteers to a meager seven minutes of study time; the other half could review the text for as long as they liked. When under pressure to read quickly, students using computers and paper performed equally well. When managing their own study time, however, volunteers using paper scored about 10 percentage points higher. Presumably, students using paper approached the exam with a more studious attitude than their screen-reading peers and more effectively directed their attention and working memory.

Even when studies find few differences in reading comprehension between screens and paper, screen readers may not remember a text as thoroughly in the long run. In a 2003 study Kate Garland, then at the University of Leicester in England, and her team asked 50 British college students to read documents from an introductory economics course either on a computer monitor or in a spiral-bound booklet. After 20 minutes of reading, Garland and her colleagues quizzed the students. Participants scored equally well regardless of the medium but differed in how they remembered the information.

Psychologists distinguish between remembering something—

a relatively weak form of memory in which someone recalls a piece of information, along with contextual details, such as where and when one learned it—and knowing something: a stronger form of memory defined as certainty that something is true. While taking the quiz, Garland's volunteers marked both their answer and whether they "remembered" or "knew" the answer. Students who had read study material on a screen relied much more on remembering than on knowing, whereas students who read on paper depended equally on the two forms of memory. Garland and her colleagues think that students who read on paper learned the study material more thoroughly more quickly; they did not have to spend a lot of time searching their mind for information from the text—they often just knew the answers.

Perhaps any discrepancies in reading comprehension between paper and screens will shrink as people's attitudes continue to change. Maybe the star of *A Magazine Is an iPad That Does Not Work* will grow up without the subtle bias against screens that seems to lurk among older generations. The latest research suggests, however, that substituting screens for paper at an early age has disadvantages that we should not write off so easily. A 2012 study at the Joan Ganz Cooney Center in New York City recruited 32 pairs of parents and three- to six-year-old children. Kids remembered more details from stories they read on paper than ones they read in e-books enhanced with interactive animations, videos and games. These bells and whistles deflected attention away from the narrative toward the device itself. In a follow-up survey of 1,226 parents, the majority reported that they and their children prefer print books over e-books when reading together.

Nearly identical results followed two studies, described this past September in *Mind, Brain, and Education,* by Julia Parrish-Morris, now at the University of Pennsylvania, and her colleagues. When reading paper books to their three- and five-year-old children, parents helpfully related the story to their child's life. But when reading a then popular electric console book with sound effects, parents frequently had to interrupt their usual "dialogic reading" to stop the child from fiddling with buttons and losing track of the narrative. Such distractions ultimately prevented the three-year-olds from understanding even the gist of the stories, but all the children followed the stories in paper books just fine.

Such preliminary research on early readers underscores a quality of paper that may be its greatest strength as a reading medium: its modesty. Admittedly, digital texts offer clear advantages in many different situations. When one is researching under deadline, the convenience of quickly accessing hundreds of keyword-searchable online documents vastly outweighs the benefits in comprehension and retention that come with dutifully locating and rifling through paper books one at a time in a library. And for people with poor vision, adjustable font size and the sharp contrast of an LCD screen are godsends. Yet paper, unlike screens, rarely calls attention to itself or shifts focus away from the text. Because of its simplicity, paper is "a still point, an anchor for the consciousness," as William Powers writes in his 2006 essay "Hamlet's Blackberry: Why Paper Is Eternal." People consistently report that when they really want to focus on a text, they read it on paper. In a 2011 survey of graduate students at National Taiwan University, the majority reported browsing a few paragraphs of an item online before printing out the whole text for more in-depth reading. And in a 2003 survey at the National Autonomous University of Mexico, nearly 80 percent of 687 students preferred to read text on paper rather than on a screen to "understand it with clarity."

Beyond pragmatic considerations, the way we feel about a paper book or an e-reader—and the way it feels in our hands—also determines whether we buy a best-selling book in hardcover at a local bookstore or download it from Amazon. Surveys and consumer reports suggest that the sensory aspects of reading on paper matter to people more than one might assume: the feel of paper and ink; the option to smooth or fold a page with one's fingers; the distinctive sound a page makes when turned. So far digital texts have not satisfyingly replicated such sensations. Paper books also have an immediately discernible size, shape and weight. We might refer to a hardcover edition of Leo Tolstoy's *War and Peace* as a "hefty tome" or to a paperback of Joseph Conrad's *Heart of Darkness* as a "slim volume." In contrast, although a digital text has a length that may be represented with a scroll or progress bar, it has no obvious shape or thickness. An e-reader always weighs the same, regardless of whether you are reading Marcel Proust's magnum opus or one of Ernest Hemingway's short stories. Some researchers have found that these discrepancies create enough so-called haptic dissonance to dissuade some people from using e-readers.

To amend this sensory incongruity, many designers have worked hard to make the e-reader or tablet experience as close to reading on paper as possible. E-ink resembles typical chemical ink, and the simple layout of the Kindle's screen looks remarkably like a page in a paper book. Likewise, Apple's iBooks app attempts to simulate somewhat realistic page turning. So far such gestures have been more aesthetic than pragmatic. E-books still prevent people from quickly scanning ahead on a whim or easily flipping to a previous chapter when a sentence surfaces a memory of something they read earlier.

Some digital innovators are not confining themselves to imitations of paper books. Instead they are evolving screen-based reading into something else entirely. Scrolling may not be the ideal way to navigate a text as long and dense as Herman Melville's *Moby Dick,* but the *New York Times,* the *Washington Post,* ESPN and other media outlets have created beautiful, highly visual articles that could not appear in print because they blend text with movies and embedded sound clips and depend entirely on scrolling to create a cinematic experience. Robin Sloan has pioneered the tap essay, which relies on physical interaction to set the pace and tone, unveiling new words, sentences and images only when someone taps a phone or a tablet's touch screen. And some writers are pairing up with computer programmers to produce ever more sophisticated interactive fiction and nonfiction in which one's choices determine what one reads, hears and sees next.

When it comes to intensively reading long pieces of unembellished text, paper and ink may still have the advantage. But plain text is not the only way to read. SA

***Ferris Jabr** is an associate editor at* Scientific American.

MORE TO EXPLORE

The Myth of the Paperless Office. Abigail J. Sellen and Richard H. R. Harper. MIT Press, 2001.

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SCIENTIFIC AMERICAN ONLINE
View a poll about people's reading habits at **ScientificAmerican.com/nov2013/read-poll**

AIR SECURITY

HACKING DRONES

Fleets of unmanned aircraft may soon scan terrain for forest fires and deliver FedEx packages. Yet drones' security flaws allow them to be readily hijacked with simple technologies

By Kyle Wesson and Todd Humphreys

Kyle Wesson is a Ph.D. candidate in electrical and computer engineering at the University of Texas at Austin. He is a member there of the Wireless Networking and Communications Group and the Radionavigation Laboratory, which develops GPS-related technologies.

Todd Humphreys is a professor of aerospace engineering at the University of Texas at Austin, where he specializes in satellite navigation and directs the Radionavigation Laboratory.

ON AUGUST 2, 2010, A U.S. NAVY HELICOPTER WANDERED LAZILY INTO THE SKIES of the highly restricted airspace that extends like an invisible dome over the American capital. The event might have merited nothing more than a routine log entry for air-traffic controllers at Ronald Reagan Washington National Airport, except for one disturbing detail. The helicopter had no human pilot. The aircraft had no cutout space for windows, and its cockpit was filled with nothing more than electronic instrumentation. It was a drone.

The MQ-8B Fire Scout, a 1,429-kilogram, 9.7-meter-long drone, had experienced what investigators later called a "software issue," whereby its communications link had been severed with human operators, who sat helplessly in a ground-control room at Naval Air Station Patuxent River in Maryland. To make matters worse, the drone failed to execute software instructions that would have forced it to return to its base. The Fire Scout, used for reconnaissance off warships, had wandered into the same airspace that Air Force One uses when it takes off from and lands at Andrews Air Force Base.

After 30 minutes of jangled nerves, the operators reestablished the communications link and took back control. Afterward, a navy official tried to put a good face on the incident by praising the drone's performance during its unexpected detour—the autopilot system kept the aircraft flying straight and level, for instance.

The Fire Scout's errant journey provides a lesson about the immense security challenges that unmanned drones pose. These iconic reconnaissance and weapon systems have now begun to take on a range of peacetime tasks. The Federal Aviation Administration estimates that more than 10,000 unmanned aircraft will fly the U.S. skyways by 2020. Drones may soon be involved in search and rescue, crop dusting, power-line monitoring, scientific research, and myriad other uses.

The logic for deploying drones is compelling. By eliminating the need for a pilot and for outfitting a cockpit and cabin to accommodate a human crew and passengers, commercial air ventures that deploy drones stand to reap enormous savings. For instance, for the price of renting a human-piloted airplane for a set of power-line inspections, a utility company could buy an entire unmanned aerial vehicle system to do the same job for years to come. The allure of drones has captured the attention of the largest U.S. corporations. FedEx founder and CEO Frederick W. Smith has talked about using drones to replace the company's fleet of package-delivery aircraft.

Even the U.S. Congress has begun to recognize the inevitability of the coming era of the commercial drone. When Congress passed the FAA Modernization and Reform Act of 2012 in February of that year, it directed the agency to draw up "a comprehen-

IN BRIEF

More than 10,000 unmanned aircraft are expected to be roving the skies by 2020 for search and rescue, power-line monitoring, scientific research and other uses that will become less costly than if the same tasks were carried out by humans.

Swarms of drones traversing U.S. airspace pose elaborate security challenges that regulatory agencies are ill prepared to face. The Federal Aviation Administration's traditional role of keeping aircraft from colliding must be extended so that drones cannot be hacked.

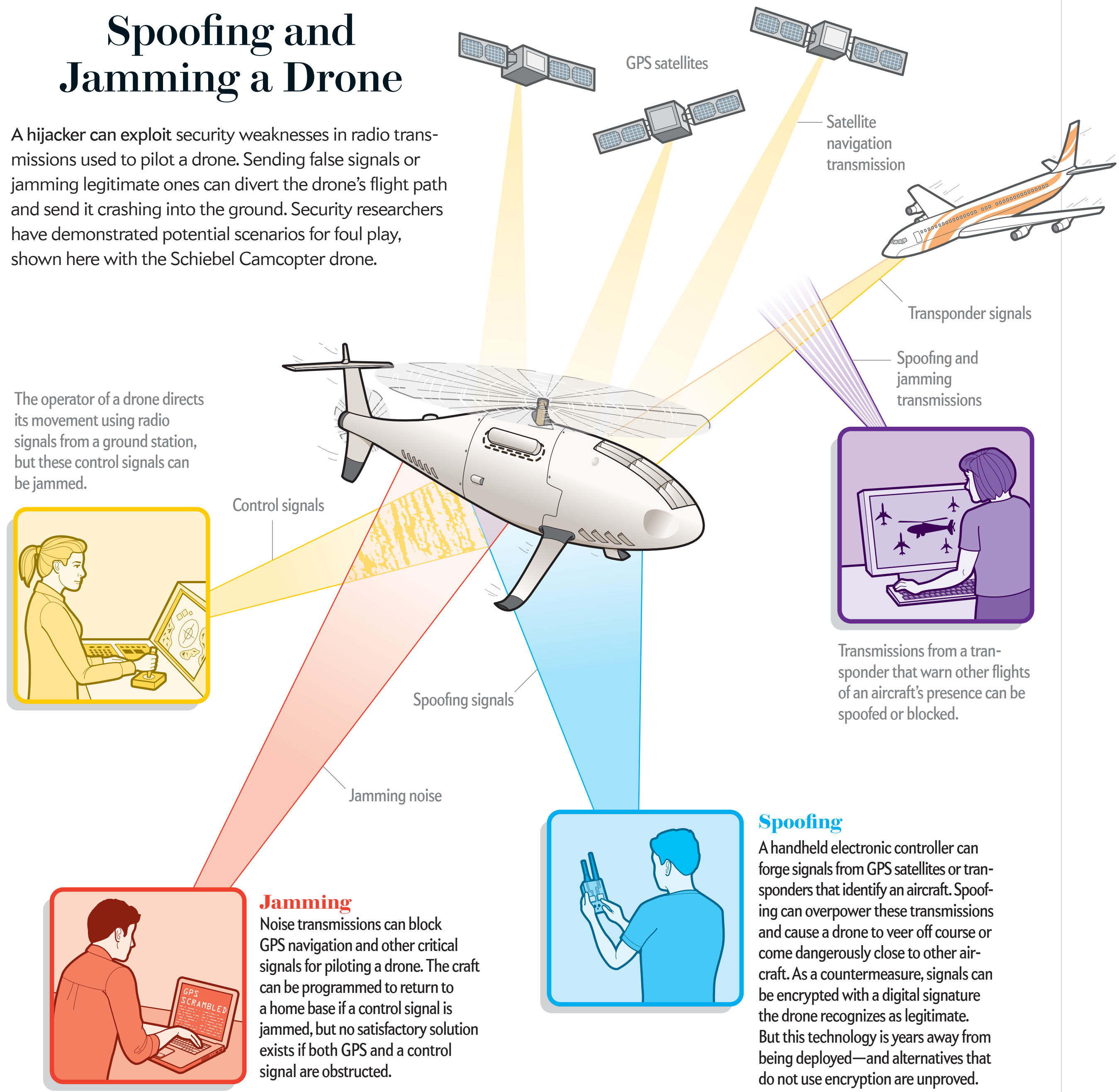
Technical steps need to be implemented to ensure that radio signals to guide and control the aircraft are made secure from being hacked or jammed by wrongdoers who wish to take over piloting of the aircraft, perhaps to use it as a weapon of terror.

PRECEDING PAGES: DAN WINTERS

VULNERABILITIES

Spoofing and Jamming a Drone

A hijacker can exploit security weaknesses in radio transmissions used to pilot a drone. Sending false signals or jamming legitimate ones can divert the drone's flight path and send it crashing into the ground. Security researchers have demonstrated potential scenarios for foul play, shown here with the Schiebel Camcopter drone.



sive plan to safely accelerate the integration of civil unmanned aircraft systems into the national airspace system" by 2015.

Unfortunately, the regulatory apparatus to manage what are essentially remote-controlled robots is unlikely to be ready in time. Drones expand the FAA's responsibilities beyond the agency's traditional role of ensuring that two Boeing 737s can keep their distance and can cope with the vicissitudes of inclement weather. Although the FAA's mission broadened considerably following the attacks of 9/11 to encompass aircraft security issues (it was the FAA that oversaw installation of reinforced cockpit doors, for instance), the prospect of swarms of drones in the sky poses more elaborate security challenges than the agency is currently ill equipped to face.

VITAL LINKS

THE MOST DAUNTING of these challenges is securing the drones' wireless links. To maneuver a drone up, down, sideways or forward requires three main communications links: the incoming navigation signal from GPS satellites, one or more signals to notify other aircraft of the drone's whereabouts, and a two-way link between ground and drone to pilot the aircraft. Disruption of any of these three can spell disaster. In some cases, more-

Illustration by Brown Bird Design

over, no clear technical solution exists to secure these links.

GPS is the linchpin of a drone's navigation system, complementing inertial guidance sensors, magnetometers, altimeters and even cameras. The GPS receiver takes pride of place in this navigation suite because, unlike the other devices, it works in all weather conditions while retaining pinpoint accuracy.

Unlike military GPS, the civil version is freely accessible and unencrypted. Continuously beamed to smartphones and sports watches alike, civil GPS is enormously popular but lacks any form of authentication, giving rise to a dangerous weakness. A fake signal can easily be substituted for the real one—a process known as spoofing.

In June 2012 at White Sands Missile Range in New Mexico, our laboratory demonstrated that vulnerability to GPS spoofing has serious consequences for unmanned aircraft. From about half a kilometer away, our spoofing device took command of an $80,000 drone. Our hand-built spoofer generated a nearly perfect forgery of the satellite signals that relay coordinates to the drone. Unable to distinguish between genuine and forgery, the drone picked our stronger signals for guidance.

Once fooled, the drone took positioning commands from our spoofing device. When signals beamed to the craft indicated falsely that it was rising vertically upward, the drone dutifully descended to maintain the desired altitude programmed into its autopilot system. By trying to adjust its location aloft based on erroneous data, the drone actually started to head directly toward the desert floor. It was only saved from crashing by an operator who was poised to override the spoofed commands and take manual control of the craft.

The danger of spoofing has been known for at least a decade. The Department of Transportation had previously documented the spoofing threat in a 2001 report, but policy makers and GPS manufacturers largely ignored that report's warnings until very recently, perhaps reasoning that an attack was too unlikely to warrant attention. Technical fixes, though, are not close at hand. Techniques that could protect GPS signals with cryptographic watermarking—a secure digital signature that identifies the origin of a signal and assures the content of its message—are years away from being implemented, and noncryptographic techniques that could be put in place sooner have yet to prove themselves

Spoofing is not the only threat that a GPS-reliant drone faces. It is also surprisingly easy to simply block reception of its navigation signals. Near the earth's surface, the signals are extraordinarily weak, having no more flux density—a measure of the signal's power—than light received from a 50-watt bulb at a distance of 22,000 kilometers. A jamming device can do its dirty work by generating noise in the same region of the radio spectrum occupied by the GPS signal. Almost any modern electronic system, even a laptop, can jam GPS signals inadvertently by sending noise into a GPS receiver at close range.

An intentional jamming device can be designed to be much more effective in confusing the drone's navigation system. In May 2012 operators in South Korea lost control of a 150-kilogram Schiebel Camcopter S-100 reconnaissance drone that crashed into its ground-control station, killing an engineer and wounding two drone operators. North Korean GPS jamming directed into South Korea most likely had precipitated a sequence of events that led to the crash, including some mistakes made by the South Korean drone operators. As this incident and our spoofing demonstration make clear, secure navigation—resistant to spoofing and jamming—will be essential before aircraft without onboard pilots can fly safely in our skies.

A recent government report warns that technology has yet to be deployed that gives a remotely piloted drone the ability to sense and avoid other aircraft in U.S. airspace.

COLLISION AVOIDANCE

THE POSSIBILITY of a midair crash between a drone and another aircraft will further complicate acceptance of drones. Traditional pilots use visual observation and radar to detect the presence of other aircraft and avoid collisions. But drones have a long way to go before they can provide that routine level of vigilance. "No suitable technology has been deployed that would furnish [unmanned aircraft] with the capability to sense and avoid other aircraft and airborne objects" while complying with FAA regulations, the federal Government Accountability Office noted in a 2012 report.

Staying out of the way of other aircraft is especially challenging for small drones because they cannot accommodate existing airborne radar systems, which are prohibitively bulky and power-hungry. Visible-light and infrared cameras offer an inexpensive and reasonably effective alternative, but they cannot see through clouds.

One solution may ultimately come from Automatic Dependent Surveillance–Broadcast, or ADS-B. An ADS-B transponder broadcasts an aircraft's position and velocity every second and receives similar reports from nearby aircraft. By 2020 the FAA will require all licensed aircraft, big or small, to operate ADS-B transponders as part of a major overhaul of the air-traffic system. So long as all nearby aircraft—whether manned or unmanned—broadcast their positions and velocities through ADS-B transponders, a collision can be avoided by using these devices to find a safe flight path.

As with civil GPS, ADS-B has a serious Achilles' heel: its transmissions are not authenticated and thus can be faked. When ADS-B was first under development in the 1990s, security was a minor concern: the idea of broadcasting fake ADS-B signals was virtually unimaginable. Yet the cost and expertise to mount an ADS-B attack have become alarmingly low. In 2012 researchers at the Air Force Institute of Technology in Ohio showed that a variety of attacks using false signals could be readily coded and transmitted from either the ground or air with a cheap antenna. Such a "false injection" attack could cause an aircraft to believe a collision was imminent.

The same technology is capable of issuing hundreds of false transmissions or preventing reception of legitimate messages. False ADS-B messages would tax small drones more than an airplane with a human pilot in the cockpit. Using onboard radar, a pilot may quickly verify whether or not a false aircraft is on a collision course, but a drone lacks a comparable backup.

The FAA wants to deal with the threat of false ADS-B messages through multilateration, a technique for locating the source of a transmission by measuring its relative arrival time at multiple ground receivers and then relaying that information aloft to an airplane. Reliable multilateration, however, depends on a precise alternative to GPS, an affordable version of which remains elusive.

Drones are controlled by a wireless tether, the so-called command-and-control radio link between the operator and the craft, which seems, at first glance, to present a lesser security challenge than does GPS or ADS-B. Secure communications protocols exist for these signals, which should suffice to ward off spoofers and other malefactors.

The signals can still be blocked, though. Loss of contact with a drone—what experts refer to as a lost link—from intentional jamming or a malfunction persists as a threat, and no satisfactory solution has emerged. Operators typically configure their drones with a lost link protocol (which prompts the aircraft, for example, to return to its base if the radio link is lost for more than 30 seconds), but such a protocol assumes that the drone's navigation system, itself subject to hacking, is operating properly and that its control system has not succumbed to a software glitch, as happened in 2010, when the Fire Scout helicopter headed toward Washington, D.C.

Another problem for regulators is finding areas of the radio spectrum that can be dedicated specifically for transmission of the command-and-control signals. Because of the scarcity of spectrum, many drones would have to resort to transmitting in unprotected radio bands used for other types of radio transmissions, which would render them susceptible to unintentional interference from the many electronic systems that already legally occupy these bands.

CHALLENGES AND MORE CHALLENGES

THE TECHNICAL COMPLEXITY of securing U.S. airways for drones bumps against a slow-moving, risk-averse bureaucracy—and a growing legislative backlash. Regulators must come to grips with a fundamental change in the way an aircraft is piloted. The ground-based drone operator, no longer a true pilot with hands on the yoke and eyes glued to the cockpit windshield, has to input a flight route into a computer, control the drone with a joysticklike device and monitor a series of communications links that wirelessly tether the aircraft to its base. At times during the course of a flight, the operator maneuvers the drone as if it were a remote-controlled hobby plane weighing, possibly, thousands of kilograms. At other moments, the drone may be flying completely autonomously.

The FAA, under the new congressional mandate, bears responsibility for making sure that the air-traffic system develops the technical wherewithal to ensure that a drone can safely share airspace with an Airbus 380 jumbo jet or a single-engine Piper Mirage. That means the FAA must come up with regulations to make certain that drones do not pose a danger if control or navigation signals are lost.

The FAA's unparalleled safety record is rooted, in part, in its intrinsic caution in adopting new technologies that could potentially disrupt the smooth functioning of the air-traffic system. Agency officials must now cope with the difficult challenge of regulating drones while they are already enmeshed in a broad-based modernization effort—the Next Generation Air Transportation System, or NextGen, that will replace radar with satellite navigation. On paper, the Department of Homeland Security would be expected to provide assistance, but officials there have stated repeatedly that they do not consider the drone issue to be part of their mission.

In crafting regulations, the FAA will have to engage in a difficult balancing of public safety considerations against the economic benefits of drone technology. A requirement that licensed, unmanned aircraft always be maintained within an operator's line of sight would make hijacking unlikely but would render drones utterly useless for many purposes. Drone technology also raises privacy issues that have never been within the FAA's purview. Privacy advocates and members of Congress are now demanding that the agency come up with regulations to deal with an aircraft that can hover above a suburban backyard while deploying high-definition cameras.

Many lawmakers, meanwhile, see no good reason to welcome the arrival of drones, having gained familiarity with them through footage on nightly newscasts that highlight their role in surveillance and missile strikes in conflict zones outside the U.S. In response, at least 42 states so far have proposed legislation imposing limits on drone use. Texas House Bill No. 912 makes it a misdemeanor for a drone operator to capture images of private property from an unmanned aircraft without the property owner's "express consent." At the federal level, the proposed Preserving American Privacy Act of 2013 would prohibit law enforcement from conducting drone-based surveillance without a warrant and would outlaw the use of armed drones by law enforcement or private citizens over the U.S.

The list of technical and regulatory demands—and the worries voiced by legislators at congressional hearings—will likely slow but fail to stop the adoption of drone technology. Some perspective is needed when considering the security of unmanned aircraft. Their vulnerabilities have longtime parallels in the world of aviation that retains captains and first officers in the cockpit. An airplane can still be hijacked, pilots coerced, communications links interrupted. Yet we continue to fly, not because we are unaware of the risks but because convenience trumps them. Drones will seek from us the same concession. SA

MORE TO EXPLORE

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SCIENTIFIC AMERICAN ONLINE
Watch a video demonstration of a drone being hacked in New Mexico at ScientificAmerican.com/nov2013/hacked

Researchers have uncovered processes that make cancer even more complicated than they thought it was

By George Johnson

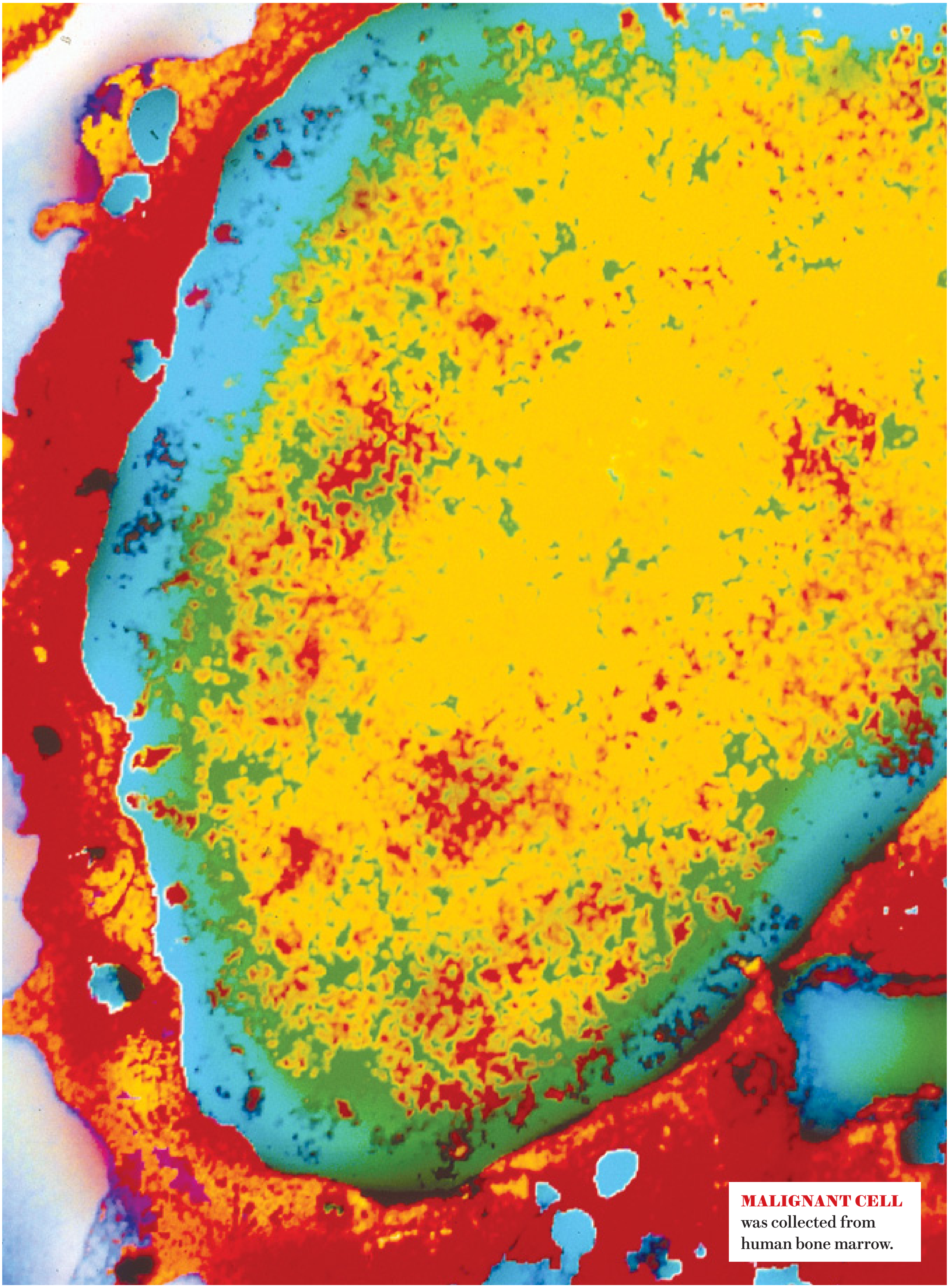
MEDICINE

THE LONG TRAIL OF CANCER'S CLUES

THINGS ARE RARELY AS SIMPLE AS THEY SEEM, AND WHAT APPEARS TO BE COMPLEX MAY BE NO MORE than ripples on the surface of a fathomless ocean. The mechanics of malignancy—a single cell acquiring mutation upon mutation until it spirals down the rabbit hole of cancer—was neatly described by two scientists, Douglas Hanahan and Robert A. Weinberg, in a sweeping synthesis published in 2000 called "The Hallmarks of Cancer."

The idea of cancer occurring as an accumulation of mutations to a normal cell goes back decades. But it was Hanahan and Weinberg who assimilated a growing mass of laboratory results and theoretical insights into six characteristics that a cancer cell must acquire as it develops into the would-be creature called a tumor. It must acquire the ability to stimulate its own growth and to ignore signals admonishing it to slow down (that is where oncogenes and tumor suppressors come in). It must learn to circumvent the fail-safe mechanisms that cause even slightly disabled cells to destroy themselves and to defeat the internal counters—the telomeres found on the ends of chromosomes—that normally limit the number of times a cell is allowed to divide. It must learn to initiate angiogenesis—the sprouting of its own blood vessels—and finally to eat into surrounding tissue and to metastasize.

More than a decade after it was published, "Hallmarks" was still the most frequently cited paper in the history of the prestigious journal *Cell,* which is as good as saying that it may be the single most influential paper on the biology of cancer. Known as the monoclonal theory (a dividing cell and its branching tree of descendants is called a clone), the picture spelled out in "Hallmarks" remains the dominant paradigm, like the big bang theory is in cosmology. Creation began as a sin-



MALIGNANT CELL was collected from human bone marrow.

MEULLEMIESTRE *Science Source*

gularity—a primordial dot of mass-energy—and ballooned to form the universe. A cancer begins with one renegade cell—it was Weinberg who popularized that term—expanding to form a tumor. With this rough map in place, the two scientists looked forward to a renaissance in the understanding of cancer:

> With holistic clarity of mechanism, cancer prognosis and treatment will become a rational science, unrecognizable by current practitioners.… We envision anticancer drugs targeted to each of the hallmark capabilities of cancer.… One day, we imagine that cancer biology and treatment—at present, a patchwork quilt of cell biology, genetics, histopathology, biochemistry, immunology, and pharmacology—will become a science with a conceptual structure and logical coherence that rivals that of chemistry or physics.

A physics of cancer! That still may happen. But in the decade and more that has passed since the paper's immodest prediction, scientists have continued to uncover whole new layers of complications.

BEYOND MUTATIONS

INSIDE THE BIOLOGICAL MICROCHIP called a cell there are components inside components and wiring so dense and so fluid that it sometimes seems impossible to tease the strands apart. Moving up a level, what is happening inside a cancer cell cannot be fully understood without considering its place within an intricate communications network of other cells. By the time the "Hallmarks" paper was published, scientists were already finding that tumors are not homogeneous masses of malignant cells—that they also contain healthy cells that help produce the proteins a tumor needs to expand and attack tissue and to plug into the blood supply. This aberrant ecosystem has come to be called the cancer microenvironment, and entire conferences and journals are devoted to understanding it.

Complicating matters further has been the gradual realization that the genetic changes that can lead to cancer do not necessarily have to occur through mutations—deletions, additions or rearrangements of the nucleotide letters in a cell's DNA. The message can be altered in more subtle ways.

Molecular tags can bind to a gene in a way that causes it to be disabled—incapable of expressing its genetic message. (The tags are methyl groups, so this process is called methylation.) Genes can also be enhanced or suppressed by twisting the shape of the genome. In the iconic image, DNA's interwoven coils float as elegantly as jellyfish in lonely isolation. But in the messiness of the cell, the two helical strands are wrapped around clusters of proteins called histones. Methyl groups and other molecules can bind to the helix itself or to its protein core and cause the whole assembly to flex. As that happens, some genes are exposed and others are obscured.

George Johnson writes regularly about science for the *New York Times*. He has also written for *National Geographic*, Slate, *Discover*, *Wired* and the *Atlantic*.

Such alterations, which change a cell's function while leaving its DNA otherwise unscathed, are called epigenetic. *Epi,* from ancient Greek, can mean "over," "above" or "on." Just as a cell has a genome, it also has an epigenome—a layer of software overlying the hardware of the DNA. Like the genome itself, the epigenome is preserved and passed on to daughter cells.

What all this research suggests is that cancer may not be only a matter of broken genes. Disturbances in a cell—carcinogens, diet or even stress—might rearrange the epigenetic tags without directly mutating any DNA. Suppose that a methyl group normally keeps an oncogene—one that stimulates cellular division—from being expressed. Remove the tag, and the cell might start dividing like crazy. On the other hand, the production of too many tags might inactivate a tumor suppressor gene that would normally hold mitosis in check. Freed to proliferate, the cell would be vulnerable to more copying errors. So epigenetic changes would lead to genetic changes—and these genetic changes could conceivably affect methylation, triggering more epigenetic changes … and round and round it goes.

Outside the laboratory, enthusiasm for this scenario is driven both by hope and by fear. Epigenetics might provide a way for a substance to act as a carcinogen even though it has been shown incapable of breaking DNA. But unlike genetic damage, these changes might be reversible. How big a role epigenetics plays remains uncertain. Like everything that happens in a cell, methylation and the modification of histones are controlled by genes—and these have been found to be mutated in different cancers as well. Maybe it all comes down to mutations after all.

On the other hand, a few scientists have proposed that cancer actually begins with epigenetic disruptions, setting the stage for more wrenching transformations.

Even more unsettling is a contentious idea called the cancer stem cell theory [see "Stem Cells: The Real Culprits in Cancer?" by Michael F. Clarke and Michael W. Becker; SCIENTIFIC AMERICAN, July 2006]. In a developing embryo, stem cells are those with the ability to renew themselves indefinitely—dividing and dividing while remaining in an undifferentiated state. When a certain type of tissue is needed, genes are activated in a specific pattern, and the stem cells give rise to specialized cells with fixed identities.

IN BRIEF

What prompts certain cells to become cancerous and grow into tumors? For a while researchers figured the answer lay entirely in the way key genes became damaged, or mutated, over time.

Over the past decade, however, investigators have uncovered many other contributing factors—from bacteria living in the intestine to epigenetic switches that turn various genes on and off.

Unraveling this growing complexity makes understanding cancer harder than ever, but it also offers unexpected avenues to explore for the development of new treatments.

Once the embryo has grown into a creature, adult stem cells play a similar role, standing ready to differentiate and replace cells that have been damaged or have reached the end of their life. Because healthy tissues arise from a small set of these powerful forebears, why couldn't the same be true for tumors?

This would be an unexpected twist on the conventional view in which any cancer cell that has acquired the right combination of mutations is capable of generating a new tumor. Imagine if instead the growth and spread of a cancer is driven by a fraction of special cells, those that have somehow become endowed with an intrinsic quality called "stemness." Only the cancer stem cells would have the ability to replicate endlessly, metastasize and seed another malignancy. How much easier that might make things for oncologists. Maybe chemotherapies fail because they spare the cancer stem cells. Remove these linchpins, and the malignancy would collapse.

Genetic changes that can lead to cancer do not have to occur through mutations. Alterations can be subtle.

As I struggled to fit this all into the big picture, I was relieved to find researchers who seemed as baffled as I was. However it all pans out, the underlying view of cancer as a Darwinian process—arising like life itself through random variation and selection—would remain unshaken. But as an outsider trying to understand the essence of cancer, I felt daunted by the possibility of even more convolutions.

In the end, all biology comes down to genes talking to genes—within the cell or from cell to cell—in a constant molecular chatter. I had not considered, however, that the genes in human tissues can also exchange information with the genes residing in the microbes that occupy our bodies. Cancer is a disease of information, of mixed-up cellular signaling. Now there is another realm to explore.

MUDDYING THE WATER

YET ANOTHER COMPLICATION has been uncovered by changes in our understanding of the biology of normal cells. For all their power to create and govern life, genes are made from combinations of just four nucleic acid letters: G, C, A and T. Each has a unique contour, and these patterns of bumps and grooves are copied from DNA to molecules known as messenger RNA and then ferried to the ribosomes, the cellular structures that use the information to make proteins. These proteins include the enzymes that help to make the genetic machinery run. The crowning simplification of the theory was what Francis Crick called the "central dogma": DNA to RNA to protein.

The complications were soon to follow. Not every bit of DNA was part of the protein code. Some sequences were used for making the messenger RNA and transfer RNA. Others served as control knobs, turning the volume of a gene up and down to modulate the production of its protein. With all of this intricate, interlocking machinery, you could almost entertain the fantasy that the whole thing was the product of an engineer. But nature was so much messier. Genes, for example, were not continuous. They were interrupted by scraps of gibberish. As the genetic message was reprinted into the messenger RNA, these blemishes—so-called introns—had to be edited out. They were accidents of evolution and of entropy. In fact, only a small percentage of the genome appeared to serve a purpose. The rest came to be known as junk DNA—a hodgepodge of genes that had become crippled and discarded over millions of years. With no compelling reason to get rid of the debris, it was carried along, generation by generation, for the ride.

It seemed barely conceivable that so much of the genome sat silent and inert. In its incessant tinkering, evolution would surely find new purposes for some of the discarded parts. Early in the 1990s scientists began to notice a new kind of RNA produced by the junk DNA. When they latched onto a messenger RNA, these molecules kept it from delivering its information. Because of their small size, they were named microRNAs. They came in different varieties, and as they increased or decreased in number they regulated the production of various proteins. Like almost everything else in the cell, they were bound to play a role in cancer. Suppose there was a microRNA whose role was to block the expression of a growth-promoting oncogene. If the cell produced too little of this regulator, that would encourage proliferation. An excess of another kind of microRNA might result in the stifling of a tumor suppressor. In fact, just one of these molecules might regulate several different genes, leading to tangles of entwined effects. Mutations to the junk DNA had been thought to be harmless. But if they upset the balance of microRNAs, they could nudge a cell toward malignancy.

Junk that is not junk. Genes—99 percent of them—that reside in our microbes rather than in our own cells. Background seemed to be trading places with foreground, and I was reminded of what happened in cosmology when most of the universe turned out to be made of dark matter and dark energy. Yet for all the new elaborations, the big bang theory itself was left standing. It wasn't so clean and simple as before, but it provided the broad strokes of the picture, a framework in which everything, aberrations and all, made sense.

The same appears to be happening with Hanahan and Weinberg's six hallmarks of cancer. In March 2011 the two scientists wrote "Hallmarks of Cancer: The Next Generation." Looking back on the decade that had elapsed since their paper, they concluded that the paradigm was stronger than ever. Certainly there were complications. Stem cells and epigenetics might come to play a greater role. In the end, there may be more than six hallmarks. The hope is that the number will be finite and reasonably small. SA

MORE TO EXPLORE

Hallmarks of Cancer: The Next Generation. Douglas Hanahan and Robert A. Weinberg in *Cell*, Vol. 144, No. 5, pages 646–674; March 2011. **www.cell.com/fulltext/S0092-8674(11)00127-9**

A Decade of Exploring the Cancer Epigenome—Biological and Translational Implications. Stephen B. Baylin and Peter A. Jones in *Nature Reviews Cancer*, Vol. 11, pages 726–734; October 2011. **www.ncbi.nlm.nih.gov/pubmed/21941284**

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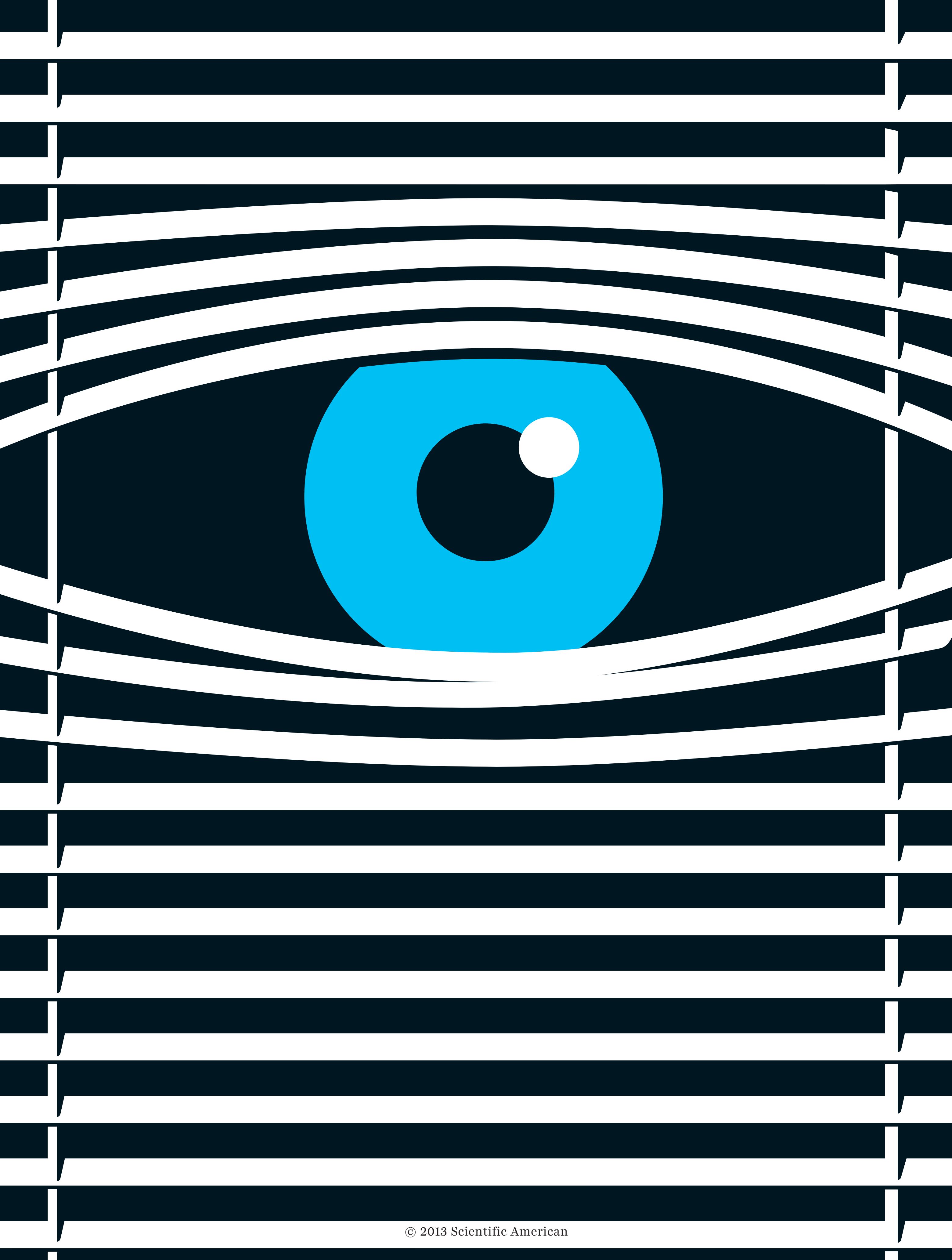
Watch Douglas Hanahan talk about the six biological hallmarks of cancer—and perhaps one or two more—at **ScientificAmerican.com/nov2013/cancer-hallmarks**



T H E B I G I D E A

SCIENCE AND SOCIETY

How Should We Think about Privacy?

Making sense of one of the thorniest issues of the digital age

By Jaron Lanier

I. IMPERFECT INFORMATION

Focusing on facts is generally an effective first step to gaining clarity about a complex or elusive topic. In the case of privacy, the facts are denied to us. Those who have reduced our privacy, whether they are state or commercial actors, prefer that we do not reduce theirs. The National Security Agency (NSA), for example, long hid the full extent of its vast electronic surveillance operations. Even after the recent leaks by former NSA contractor Edward J. Snowden, we can know only approximately what is going on.

No single observer has a complete picture of who has gathered what data about whom in our world today. Certain organizations, such as the NSA, know immensely more than anyone else, but not even they know the full range of algorithms that commercial and government entities have applied to personal data or to what effect.

Therefore, privacy is, for now, a murky topic that can be investigated only in a prescientific manner. We must rely more than we might prefer to on theory, philosophy,

Illustrations by Noma Bar

introspection and anecdotes. But this does not mean that we cannot think.

II. WHAT IS PRIVACY?

A philosophy of privacy is a cultural badge. Growing up in New Mexico, I lived with some native Pueblo people one summer. They complained that anthropologists had done more damage to their culture than missionaries because it was the anthropologists who published their secrets. And yet the elderly couple who told me this had a son who had become an anthropologist. Meanwhile Chinese students in the U.S. used to barge into rooms without knocking, unable to comprehend why this wasn't acceptable. That has changed, as has China.

These days the young and geeky are sometimes said to care less about privacy than their elders. An older person who grew up in a world without wearable computing is more likely to feel violated when confronted with a face-mounted camera. Companies such as Facebook have been criticized—or praised—for socializing young people to be comfortable with the activities of the NSA and other intelligence agencies. The group that promotes privacy most intensely and from the grass roots may be gun owners, who fear that being placed on a government list might eventually lead to confiscation of their firearms.

Despite the variety of attitudes toward privacy, talk of policy matters usually leads to a discussion of trade-offs. If the state must be able to analyze everyone's personal information to catch terrorists before they act, then individuals cannot be entitled to both privacy and safety. Or at least this is the way the trade-off is often framed.

Something is askew in thinking about privacy this way. Considered in terms of trade-offs, privacy inevitably ends up being framed as a culturally sanctioned fetish—an adult security blanket. How much privacy are people "willing to give up" for certain benefits? Implicit in this formulation is the notion that any desire for privacy might be an anachronism, like the blind spot in the human retina. This is akin to asking how ill tasting a medicine a patient is willing to drink to cure a serious disease. The implication is that the patient ought to stop being so delicate. A kindred claim holds that if people "would only share more," they could enjoy more convenience or create more value in online networks.

It is tempting to dismiss subjective feelings about privacy because they are fickle, but that might be a mistake. What if there is value in different people or cultures maintaining different practices around privacy? Cultural diversity, after all, should be treated as an intrinsic good. To think otherwise is to assume that culture, thought and information habits are already as good as they could possibly be—that only one stance regarding privacy, whatever it may be, is the right one. An ecologist would never think that evolution had reached its conclusion. Perhaps, then, not everyone should be herded into a single ethic of information. Perhaps people should be free to choose among varying degrees of privacy.

III. PRIVACY AS POWER

In the information age, privacy has come to mean, nakedly, information available to some but unavailable to others. Privacy is the arbiter of who gets to be more in control.

Information has always been an important tool in contests for wealth and power, but in the information age it is the most important tool. Information supremacy becomes harder to distinguish from money, political clout or any other measure of power. The biggest financial schemes are also the most computational; witness the rise of high-frequency trading. Big computation has not just benefited occasional firms but has had a macroeconomic effect because it has amplified the scale of the financial sector so impressively. Companies such as Google and Facebook sell nothing but computation designed to improve the efficacy of what we still call "advertising," although that term has less and less to do with persuasion through rhetoric or style. It has instead come to mean directly tweaking what information people are exposed to conveniently. Similarly, modern elections rely on large-scale computation to find persuadable voters and motivate them to turn out. Privacy is at the heart of the balance of power between the individual and the state and between business or political interests.

This state of affairs means that unless individuals can protect their own privacy, they lose power. Privacy has become an essential personal chore that most people are not trained to perform. Those in the know do a better job of staying safe in the information age (by discouraging identity theft, for instance). There-

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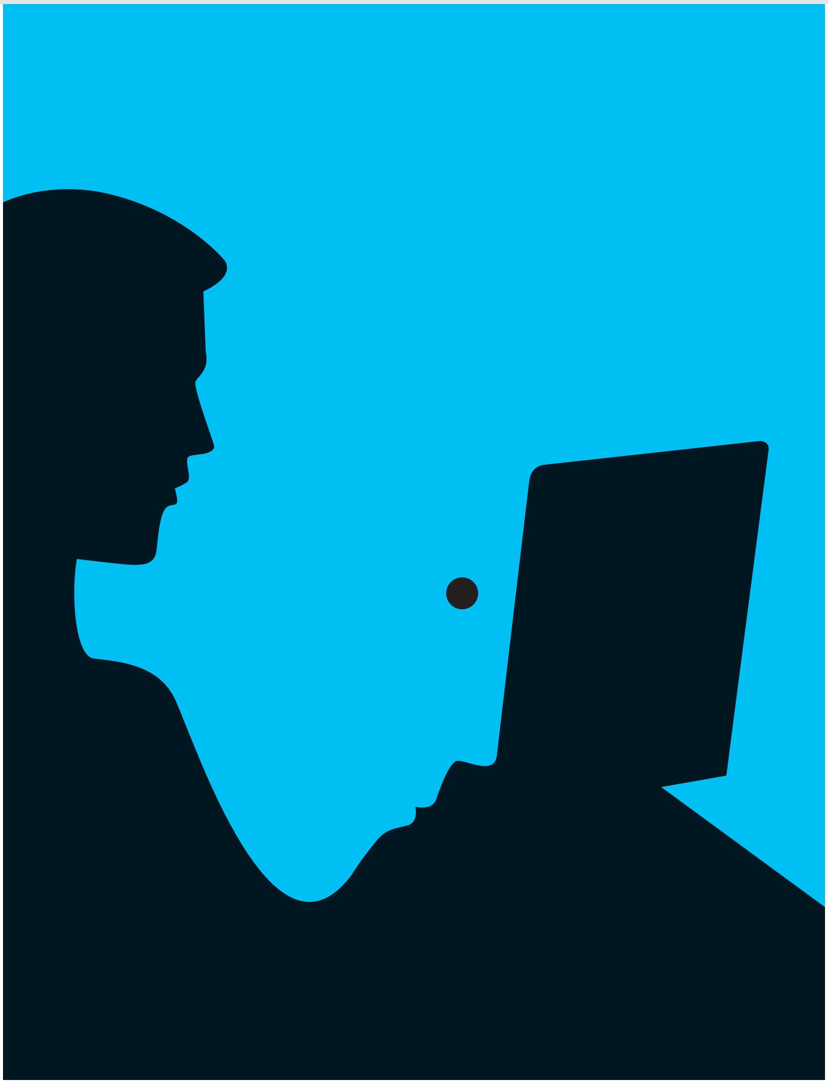
IN BRIEF

Privacy is not yet dead. But the choices we make today about the role of privacy in our networked era will have consequences for decades to come.

We should avoid speaking of privacy in terms of trade-offs, in which the more privacy we give up, the more benefits (in terms of security, for example) we get in return. Those benefits are often exaggerated.

Rather than imposing a single ethic of privacy on every person, we should allow people to choose among varying levels of privacy.

Monetizing personal information would put people in control of their own data, enabling them to choose their own level of privacy. Meanwhile data would become too expensive for businesses and governments to hoard and mine indiscriminately.



Facebook and its competitors promote openness and transparency to their users but hide predictive models of those users in deep, dark basements.

fore, society has taken on a bias in favor of a certain kind of technically inclined person—not just in the job market but in personal life.

Some cyberactivists argue that we should eliminate secrets entirely. But young techies who declare that sharing is wonderful are often obsessive about blocking the spybots that infest most Web sites or using encryption to communicate electronically. In this, the young techies and the biggest tech companies are similar. Facebook and its competitors promote openness and transparency to their users but hide predictive models of those users in deep, dark basements.

IV. THE ZOMBIE MENACE

We are cursed with an unusually good-natured technical elite. The mostly young people who run the giant cloud computing companies that provide modern services such as social networking or Web searching, as well as their counterparts in the intelligence world, are for the most part well intentioned. To imagine how things could go bad, we have to imagine these charming techies turning into bitter elders or yielding their empires to future generations of entitled, clueless heirs. It should not be hard to fathom, because such scenarios have happened as a rule in human history. It feels heartless to think that way when you know some of the nice sorts of techies who thrive in our computation-centric times. But we have to do our best at thinking dark thoughts if we are to have any forethought about technology at all.

If an observer with a suitably massive computer obtained enough personal information about someone, that observer could hypothetically predict and manipulate that person's thoughts and actions. If today's connected devices might not be up to the task, tomorrow's will be. So suppose some future generation of hyperconvenient consumer electronics takes the form of a patch on the back of the neck that directly taps into the brain to know, prior to self-awareness, that one is about to ponder which nearby café to visit. (Bringing relief to this darkest of dilemmas has become the normative challenge for consumer technology in our times.)

Many of the components to create such a service exist already. At laboratories such as neuroscientist Jack Gallant's at the University of California, Berkeley, it is already possible to infer what someone is seeing, or even imagining, or about to say, merely by performing "big data" statistics correlating present functional magnetic resonance imaging measurements of the brain with the circumstances of previous measurements. Mind reading, of a sort, has therefore already been accomplished, based on statistics alone.

Now let us suppose that while wearing this hyperconvenient device, you are about to decide to go to a café, only you do not know it yet. And let us suppose that some entity—some Facebook or NSA of the future—has access to that device and an interest in steering you away from café A and toward café B. Just as you are about to contemplate café A, a nagging message from your boss pokes up in your head-up display; you become distracted and frustrated, and the thought of going to café A never actually comes to mind. Meanwhile a thought about café B releases a tweet from some supposed hot prospect on a dating site. Your mood brightens; café B suddenly seems like a great idea. You have become subject to neo-Pavlovian manipulation that takes place completely in a preconscious zone.

The point of this thought experiment, which has a long pedigree in science fiction, is that computing and statistics could effectively simulate mind control. It is arguable that a regime of cloud-driven recommendation engines in ever more intimate portable devices could get us part of the way in the next few years to the mind-control scenario just described.

V. PLAGUE OF INCOMPETENCE

The traditional, entertaining way to tell a cautionary science-fiction tale is to conjure an evil villain who becomes all-powerful. Instead of considering that potential dark future, I will focus on a scenario that is not only more likely but that has already manifested in early forms. It is less an evil scheme orchestrated by hypercompetent villains and more like a vague plague of incompetence.

In such a scenario, an entity or, say, an industry would devote tremendous resources to the algorithmic manipulation of the masses in pursuit of profit. The pursuit would indeed be profitable at first, although it would eventually become absurd. This has already happened! Look no further than the massive statistical calculations that allowed American health insurance companies to avoid insuring high-risk customers, which was a profitable strategy in the near term—until there came to be an unsustainable number of uninsured people. Society could not absorb the scheme's success. Algorithmic privacy destruction as a means to wealth and power always seems to end in a similar massive bungle.

Consider the state of modern finance. Financial schemes relying on massive statistical calculations are often successful at first. With enough data and computation, it is possible to extrapolate the future of a security, the behavior of a person or really any smoothly varying phenomenon in the world—for a time. But big data schemes eventually fail, for the simple reason that statistics in isolation only ever represent a fragmentary mirror of reality.

Big data finance was not based on encroaching on individual privacy (by, for example, modeling individuals and targeting them with stupid mortgages and credit offers) until the beginning of the 21st century. Prior to that, it was more abstract. Securities were modeled, and investments in them were managed automatically, absent any understanding of what was actually being done in the real world as a result. Greenwich, Conn.–based hedge fund Long-Term Capital

Management was an early example. It was a spectacular high flier until it failed in 1998, requiring a stupendous bailout from taxpayers. (High-frequency trading schemes are now reinitiating the pattern with bigger data and faster computation.) Now, however, much of the world of highly automated finance relies on the same massive individual privacy evaporation that is characteristic of spy craft or the consumer Internet. The mortgage-backed securities that led to the Great Recession finally joined personal-privacy violation to automated trading schemes. Another cosmic-scale bailout at the public's expense occurred, and similar future bailouts will follow, no doubt.

This is not a story of an ultracompetent elite taking over the world. Instead it is a story of everyone, including the most successful operators of giant cloud services, having trouble understanding what is going on. Violating everyone else's privacy works at first, creating fortunes out of computation, but then it fails. This pattern has already created financial crises. In the future, when whoever runs the most effective computers with the most personal data might be able to achieve a greater degree of prediction and manipulation of the whole population than anyone else in society, the consequences could be much darker.

VI. THE TRUE MEASURE OF BIG DATA

When somebody is selling the abilities of a service that gathers and analyzes information about vast numbers of other people, they tend to adopt a silly, extreme braggadocio. To paraphrase the sort of pitch I have heard many times, "Someday soon, if not already, giant computers will be able to predict and target consumers so well that business will become as easy as turning a switch. Our big computer will attract money like iron filings to a magnet."

For instance, I have been present when a Silicon Valley start-up, hoping to be acquired by one of the big players, claimed to be able to track a woman's menstrual cycle by analyzing which links she clicked on. The company said it could then use that information to sell fashion and cosmetics products to her during special windows of time when she would be more vulnerable to pitches. This scheme might be valid to a point, but because it relies purely on statistics, with no supporting scientific theory, it is impossible to know what that point is.

Similarly, when selling a system that gathers information about citizens, a government agency—or more likely, a private contractor serving an agency—might make colorful claims about catching criminals or terrorists before they strike by observing and analyzing the entire world. The terminology of such programs ("Total Information Awareness," for instance) reveals a desire for a God-like, all-seeing perch.

A stupendous amount of information about our private lives is being stored, analyzed and acted on in advance of a demonstrated valid use for it.

Science fiction has contemplated this kind of thing for decades. One example is the "precrime" unit in *Minority Report,* a movie, based on a 1956 short story by Philip K. Dick, that I helped to brainstorm many years ago. The precrime unit caught criminals before they had the chance to act. But let us be clear: this is not what giant systems for data gathering and analysis actually do.

The creators of such systems hope that one day metadata will support a megaversion of the kind of "autocomplete" algorithms that guess what we intend to type on our smartphones. Statistical algorithms will fill holes in the data. With the aid of such algorithms, studying the metadata of a criminal organization ought to lead us to new, previously unknown key members.

But thus far, at least, there appears to be no evidence that metadata mining has prevented a terrorist act. In all the cases we know about, specific human intelligence motivated direct investigations that led to suspects. In fact, when responsible officials from the various giant cloud computer projects, whether private or governmental, describe what they do, the claims come rapidly down to earth, especially under careful reading. Yes, once there are leads about a potential terrorist plot, it is faster to connect the dots with a giant database readily at hand. But the database does not find the leads in the first place.

One often sees a parlor trick these days: an after-the-fact analysis of historical events that purports to show that big data would have detected key individuals in plots before they occurred. An example is that algorithmic analysis of Paul Revere's contemporaries reveals that Revere was a central connecting figure in a social network. The datum in this case is his membership in various organizations before the American Revolutionary War. Seoul National University sociologist Shin-Kap Han demonstrated that analysis of a rather small database of memberships in varied prerevolutionary organizations singles out Revere as a unique connecting figure. More recently, Duke University sociologist Kieran Healy independently derived similar results from a slightly divergent database representing the same events.

Sure enough, there is Paul Revere, placed right in the middle of the clusters connecting other individuals. Such results advertise the application of metadata to security. Still, there are several factors to consider before being persuaded that this type of research can predict events before they happen.

Revere was clearly in a special position to be a linchpin for something. Lacking any historical context, however, we would not know what that thing might be. A similar centrality might accrue to the individual who was able to procure the best ales. Metadata can only be meaningful if it is contextualized by additional sources of information. Statistics and graph analyses cannot substitute for understanding, although they always seem to for a little while.

The danger is that big data statistics can create an illusion of an automatic security-generating machine, similar to the illusion of guaranteed wealth machines that Wall Street is always chasing. A stupendous amount of information about our private lives is being stored, analyzed and acted on in advance of a demonstrated valid use for it.

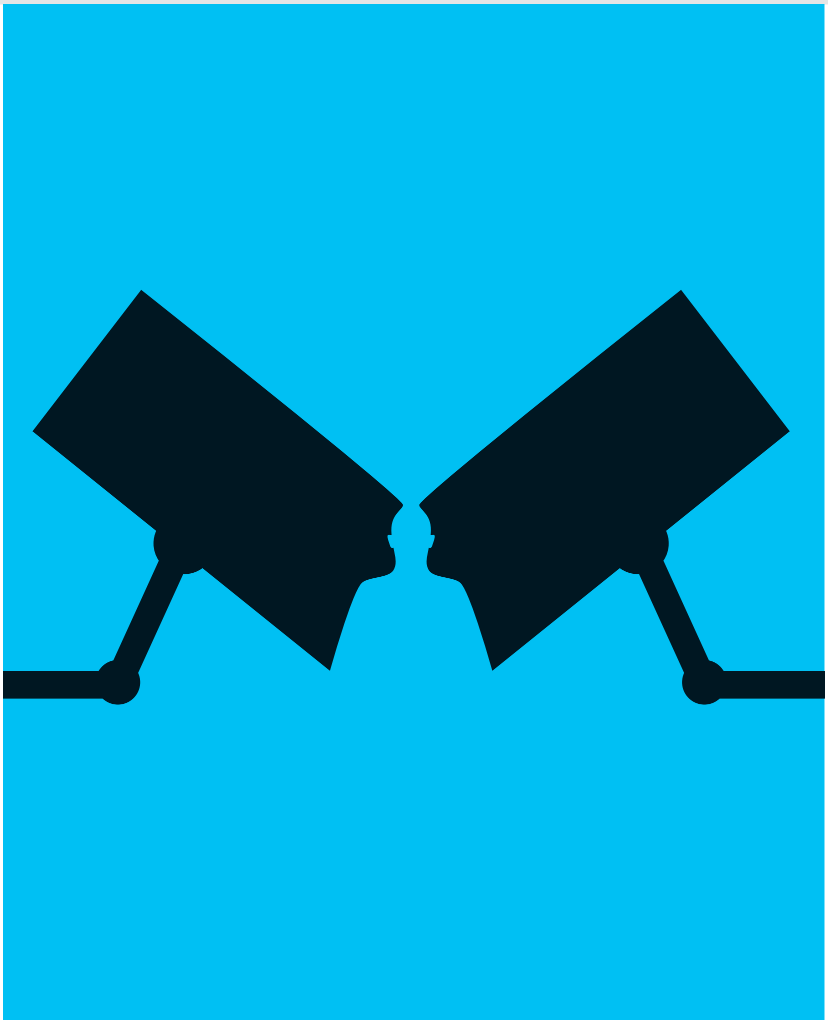
VII. SOFTWARE IS LAW

One frequently hears statements of this sort: "The Internet and the many new devices communicating through it will make personal privacy obsolete." But that is not necessarily so. Information technology is engineered, not discovered.

It is true that once a network architecture is established, with many users and practically uncountable interconnecting computers relying on it, changes can be difficult to achieve. The architecture becomes "locked in." The nature of privacy in our digital networks, however, is not yet fully locked in. We still have the potential to choose what we want. When we speak about grand trade-offs between privacy and security or privacy and convenience, it is as if these trade-offs are unavoidable. It is as if we have forgotten the most basic fact about computers: they are programmable.

Because software is the way people connect and get things done, then what the software allows is what is allowed, and what the software cannot do cannot be done. This is particularly true for governments. For instance, as part of the Affordable Care Act, or Obamacare, smokers in some states will in theory pay a higher price for health insurance than nonsmokers. The reason it is only "in theory" is that the software that will run the new legal framework for health care finance in the U.S. was not written to accommodate the penalty for smokers. So the law will have to go into effect without the penalty, awaiting some moment in the future when the software is rewritten. Whatever anyone thinks about the law, it is the software that determines what actually happens.

The example of the penalty for smokers just hints at a larger issue. Quirks in the software that implements Obamacare or any other society-scale project could determine more about the experiences of individuals in a society than the intent of politicians.



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VIII. HOW TO ENGINEER THE FUTURE WHEN WE DON'T KNOW WHAT WE'RE DOING

There are two primary schools of thought for how to get value from big data without creating too much collateral damage in the form of privacy violation. One seeks to articulate and enforce new regulations. The other seeks to foster universal transparency so that everyone will have access to all data and no one will gain an undue advantage. These two efforts are for the most part tugging in opposite directions.

The problem with privacy regulations

is that they are unlikely to be followed. Big data statistics become an addiction, and privacy regulations are like drug or alcohol prohibitions. One disheartening aspect of the periodic leaks related to the NSA is that even secret rules and regulations embraced by the organization seemed to be futile. NSA employees used their perches to spy on romantic interests, for instance. Nevertheless, perhaps some new regulations and oversight could do some good.

But what of the opposite idea—making data openness more common? The problem with that approach is that it is not just access to data that matters. More important is the computing power used to analyze those data. There will always be someone with the most effective computer, and that party is unlikely to be you. Openness in the abstract only reinforces the problem because it heightens the incentive to have the biggest computer.

Let us take the ideal of openness to the logical extreme. Suppose the NSA published the passwords to all its internal servers and accounts tomorrow. Anyone could go take a look. Google and its competitors would immediately scrape, index and analyze the vast data stored by the NSA better than you could, and they would be happy to earn fortunes from customers who would leverage that work to find some way to manipulate the world to their advantage instead of to yours. Remember, big data in the raw does not bring power. What brings power is big data *plus* the very most effective computers, which are generally the giant ones you do not own.

Is there a third alternative? It is almost universally received wisdom that information should be free, in the commercial sense. One should not have to pay for it. This is what has allowed the giant Silicon Valley online companies to rise up so quickly, for instance.

It is worth reconsidering this orthodoxy. Allowing information to have commercial value might clarify our situation while bringing an element of individuality, diversity and subtlety back to questions of privacy.

If individuals were paid when information derived from their existence was used, that might cancel out the motivations to create grand big data schemes that are doomed to fail. A data scheme would have to earn money by adding value rather than using information owned by individuals against them.

This is a subtle concept, and I have been exploring it in detail in a collaboration with Palo Alto Research Center and Santa Fe Institute economist W. Brian Arthur and Eric Huang, a Stanford University graduate student. Huang has extended the most accepted models of insurance businesses to see what happens when information takes on a price. While the results are complex, an overall pattern is that when insurance companies have to pay people for their information they cannot cherry-pick as easily, so they will cover people they would otherwise exclude.

It is important to emphasize that we are not talking about redistributing benefits from the big guys to the little guys; instead this is a win-win outcome in which everyone does better because of economic stability and growth. Furthermore, it is inconceivable to have enough government inspectors to confirm that privacy regulations are being followed, but the same army of private accountants that make markets viable today could probably handle it.

If information is treated as something that has commercial value, then principles of commercial equity might resolve otherwise imponderable dilemmas related to privacy. In our current world, it is very hard to create an in-between level of privacy for oneself without significant technical skills. A nontechnical person must either join a social network or not and can find it difficult to manage privacy settings. In a world of paid information, however, a person might tweak the price of her information up or down and thereby find a suitable shade of gray. All it would take is the adjustment of a single number, a price.

Someone wants to take a picture of you with a face-mounted camera? In the abstract, they could, but to actually look at the picture, to *do* anything with it, might cost a prohibitive amount. Individuals might miss out on some benefits by setting the price of their information too high, but this is one way cultural diversity can come about even when there are sensors connected to big computers everywhere.

There is also a political angle: when information is free, then the government becomes infinitely financed as a spy on the people because the people no longer have the power of the purse as a means to set the scope of government. Put a price on information, and the people can decide how much spying the government can afford simply by setting the tax rate.

This briefest presentation can only hint at the idea of paid information, and many questions would remain even if I went on for many more pages, but the same can be said for the alternatives. No approach to the quandary of privacy in the big data age, neither radical openness nor new regulation, is mature as yet.

It is immensely worth looking for opportunities to test all the ideas on the table. Network engineers should also build in any software "hooks" we can, whether they will ever be used or not, so that network software will be able to support future ideas about paid information, increased regulation or universal openness. We must not rule anything out if we can possibly help it.

We who build big data systems and devices that connect to them face a tricky situation that will only become more common as technology advances. We have very good reasons to do what we do. Big data can make our world healthier, more efficient and sustainable. We must not stop. But at the same time we must know that we do not know enough to get it right the first time.

We must learn to act as though our work is always a first draft and always do our best to lay the groundwork for it to be reconsidered, even to be radically redone. SA

MORE TO EXPLORE

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Who Owns the Future? Jaron Lanier. Simon & Schuster, 2013.

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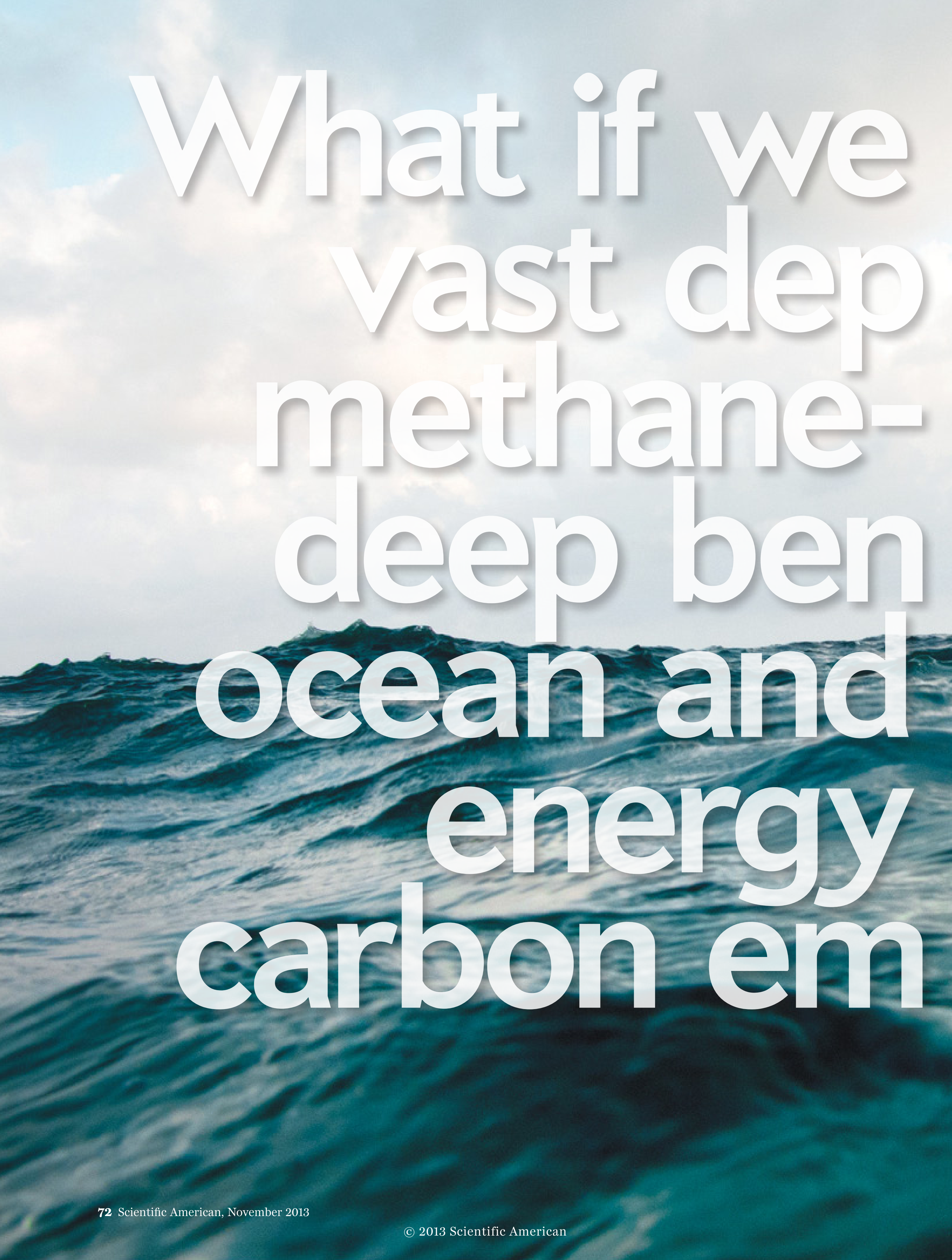
To listen to an interview with Lanier, go to **ScientificAmerican.com/nov2013/lanier**



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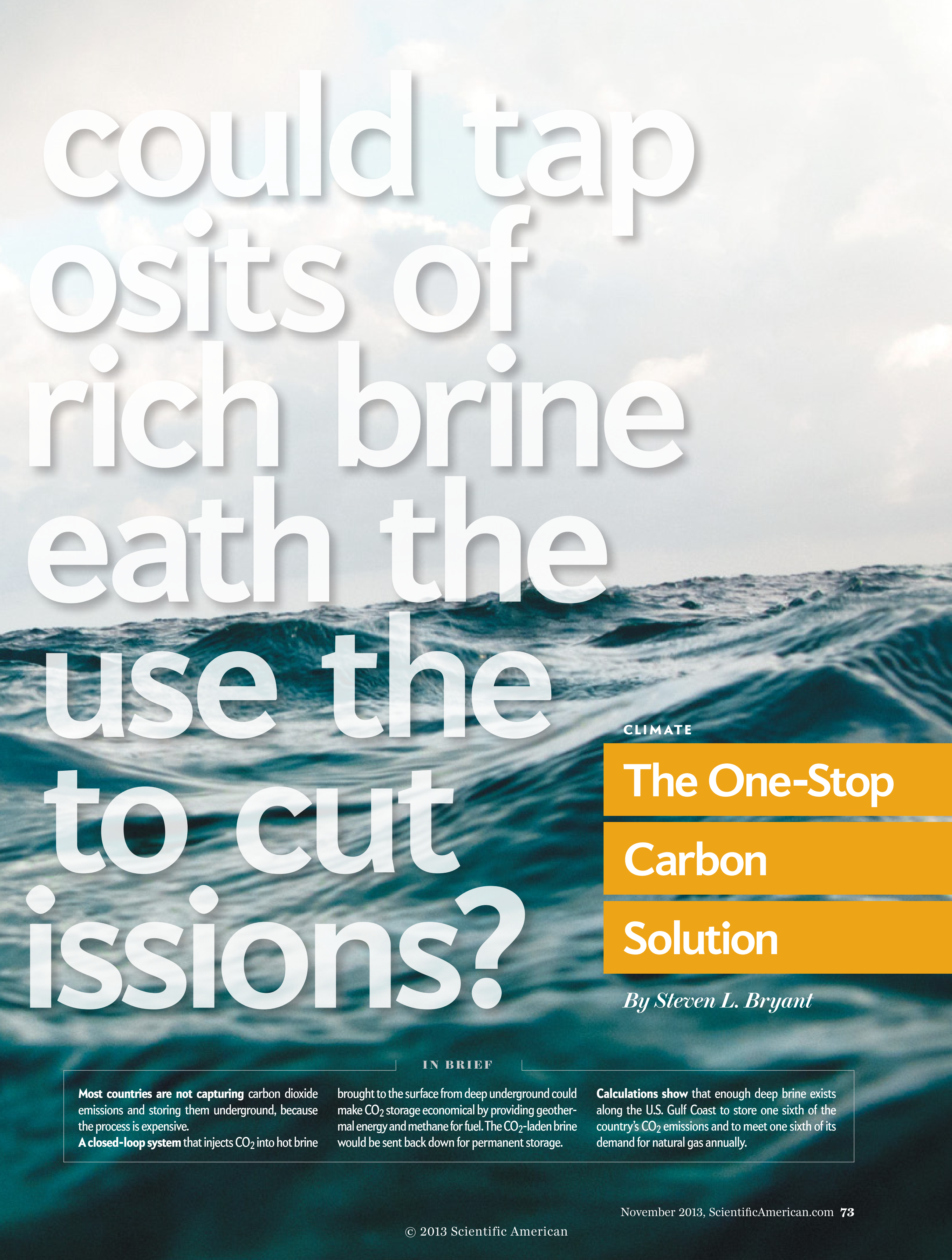

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CLIMATE

The One-Stop Carbon Solution

By Steven L. Bryant

IN BRIEF

Most countries are not capturing carbon dioxide emissions and storing them underground, because the process is expensive.

A closed-loop system that injects CO_2 into hot brine brought to the surface from deep underground could make CO_2 storage economical by providing geothermal energy and methane for fuel. The CO_2-laden brine would be sent back down for permanent storage.

Calculations show that enough deep brine exists along the U.S. Gulf Coast to store one sixth of the country's CO_2 emissions and to meet one sixth of its demand for natural gas annually.

Steven L. Bryant is a professor of petroleum and geosystems engineering at the University of Texas at Austin, where he directs the Center for Frontiers of Subsurface Energy Security and runs an industry-sponsored research program, both focused on geologic carbon dioxide storage.

MARK TWAIN, IT IS CLAIMED, OBSERVED THAT EVERYBODY COMPLAINS ABOUT THE WEATHER, but nobody does anything about it. A modern-day Twain might remark that everybody talks about climate change, but nobody is taking serious action. One big reason is economics. Reducing the buildup of carbon dioxide in the atmosphere—the major human-based driver of climate change—requires an expensive shift away from coal and oil as our prime sources of energy. Or it requires costly technology to capture CO_2 as industry emits it and then store the gas where it will stay put for centuries to come.

Yet what if a technology could economically do both: produce large amounts of energy and significantly reduce greenhouse gas emissions? And what if that technology fit seamlessly into the country's existing industrial infrastructure? This scenario could become reality along the U.S. Gulf Coast. Because of a special geologic situation there, a huge amount of CO_2 could be stored several kilometers underground in hot, salty fluid called brine, and the storage procedure itself would produce a vast amount of methane for fuel, as well as usable heat. Neither the storage nor the production of methane or of geothermal energy is economical on its own. Yet new calculations show that when the processes are combined in a closed-loop system, they could pay off handsomely in the U.S. and elsewhere.

GRAVITY RULES

WAIT, METHANE? The latest villain of climate change? The gas that can escape from pipelines and from gas wells in hydraulically fractured shale and that, molecule for molecule, has 20 times the global-warming power of CO_2? Yes.

To understand the logic, first take a look at capturing and burying carbon, known as sequestration. Thinking about the challenges is what led my colleagues and me to propose a seemingly heretical system.

The goal of carbon capture and storage is to grab CO_2 molecules at the source–the flue gas that rises from a fossil-fuel power plant—and lock them away so they do not enter the atmosphere. "Storage" sounds straightforward, but the only repository anywhere near big enough to house the incredible volume of CO_2 is underground. Scientists have determined that the pores of sedimentary rock in the top few kilometers of the earth's crust could theoretically hold centuries' worth of CO_2 emissions.

To meet a target of storing, say, 15 percent of U.S. emissions, up to a gigaton of CO_2 would have to be sequestered a year. The global energy industry produces about four gigatons of crude oil and two gigatons of natural gas from sedimentary rocks every year. The scale of this activity indicates that moving a gigaton of compressed CO_2 into the earth's crust should be achievable, although the effort would be enormous. Of course, other changes at a comparable scale, such as improving energy efficiency and switching to nonfossil fuels, would reduce the CO_2 created in the first place.

The next step seems obvious: start adapting proved oil and gas production technologies to implement this form of geologic carbon storage—and start now. Unfortunately, this strategy faces a fundamental disadvantage. Over time the CO_2 would tend to rise back toward the surface through fissures and pores, eventually escaping from the ground into the atmosphere unless it encountered a "seal"—a layer of rock with pores so tiny that the gas could not push through it.

Our petroleum industries rely on such natural upward flows. The oil and gas in underground reservoirs arrived there from even deeper rocks along various conduits. In this long, slow, upward cascade, some fluid gets trapped, but much of it keeps migrating until it reaches the surface. Most prospectors, during the early oil industry, drilled where they spotted surface seeps.

Widespread study of underground CO_2 plumes by various scientists shows a similar situation: many geologic structures will stop CO_2 from rising, but conduits will also permit upward movement. Yet engineers could exploit an interesting quirk of CO_2. Most liquids become less dense when gas dissolves into them. But when CO_2 dissolves into water, the liquid becomes denser. Most watery liquid that is deep underground is brine, and when CO_2 dissolves into the salty fluid the brine also becomes denser. The buoyancy problem disappears; CO_2 stored in this form would tend to sink, moving away from the earth's surface and thereby enhancing storage security.

ENERGY COVERS THE COST

THE CATCH is that CO_2 takes a long time to dissolve on its own into deep brine at the typical temperatures and pressures where it exists. So Mac Burton, then my graduate student, and I considered a radical idea: drill a well down into the brine, bring it up to the surface, pressurize it, inject CO_2 (which dissolves quickly in a mixing tank) and send the brine back down underground.

Obviously, this plan would require a lot of energy. And brine can hold relatively little CO_2 by weight, so large quantities would have to be moved. Either challenge could be a deal breaker.

The solution to the second challenge did not seem excessively daunting. Oil companies, for example, commonly drill wells in an evenly spaced pattern across a reservoir. Water or brine is injected down a subset of the wells to push underground oil through

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the reservoir and up through the other wells in the pattern. Currently the industry injects about 10 gigatons of brine into reservoirs a year—most of it tapped from the reservoirs themselves. Thus, achieving the brine-flow rates needed for meaningful CO_2 storage is feasible. One subset of wells at a storage site would extract brine from a reservoir; another subset would simultaneously inject brine containing dissolved CO_2.

The other challenge—the capital needed to drill all those wells and the energy needed to run them—was much harder to justify. Industry has not been rushing to capture and store CO_2, because emitters pay no penalty or price for sending CO_2 into the atmosphere. Industry has no economic reason to sequester the emissions. Policy arguments for protecting the planet or for covering the "full cost" of fossil-fuel use, which includes altering the environment, have not persuaded anyone to impose a price. At first glance, we saw no way to pay for injecting CO_2 into brine.

Not long ago, however, an idea emerged in an office down the hall from mine at the University of Texas at Austin that promised to resolve the dilemma. Gary Pope—a fellow petroleum engineering professor who has devoted most of his career to developing better ways to push oil out of reservoirs—realized that a hidden resource could be exploited.

The Gulf of Mexico, along with every other oil-producing region in the world, has deep, saline aquifers that are rich in dissolved methane. Methane is the main component of natural gas, so it can be burned in local power plants or readily distributed nationwide through the U.S.'s extensive network of gas pipelines. As the brine reached the surface, we could pull out the methane and replace it with CO_2. Even at the prevailing low prices for natural gas, revenue from the methane and geothermal heat could exceed the cost of sequestering CO_2. Whether capital costs would be passed on to ratepayers, as they often are for power plants, would depend on local regulations.

The obvious next question was whether the process could indeed pay for itself. Pope and I quickly engaged a graduate student, Reza Ganjdanesh, to find an answer.

Natural forces were in our favor. With conventional drilling, brine that rises up in a production well gradually drops in pressure and releases some of its methane. Dissolving CO_2 into brine forces out even more methane. Furthermore, many aquifers deeper than three kilometers along most of the Texas and Louisiana coasts are at high pressure, so little, if any, energy would be needed to bring the brine to the surface.

The same aquifers are also hot enough for the brine to be a good source of geothermal energy. Ganjdanesh calculated that the combined process—energy produced from methane and hot water as CO_2 was injected into the same fluid—yielded substantially more energy than was needed for the operation. This energy-positive form of geologic carbon storage could be economically attractive even in a world with no price on carbon emissions.

DRILLING DOWN THE PYRAMID

THE APPROACH also makes sense as way of providing untapped fuel. "The easy oil is gone" is a familiar refrain in the fossil-fuel industry. The easy gas is gone, too. For decades the industry drilled down into the most accessible, most concentrated and most easily extracted deposits of oil and gas, which readily rose up production pipes to the surface. As companies depleted those deposits, they moved down the "resource pyramid" to less accessible forms of fossil fuels. In the past three to five years increases in U.S. oil and gas production have come mostly from the hydraulic fracturing of deep shale. Recovering anything from this rock is slow and arduous, and the oil and gas are much less concentrated, but fracking for shale gas is the next logical step down the pyramid. We are moving there by necessity because demand keeps growing and the old, easy supplies are disappearing.

The resource pyramid has a tantalizing quality, however. The total mass of the resource typically grows as recovery gets harder. The sheer volume of natural gas locked up in shale reservoirs, for example, makes it an attractive target even though a shale gas well produces energy much less efficiently than a conventional gas well does.

Methane dissolved in brine is the next level down the pyramid after shale gas. The concentration of gas is about five times less than in shale, but the amount of methane is staggering. Estimates for the Gulf Coast alone range from several thousand to several tens of thousands of trillion cubic feet (Tcf) of methane. For perspective, in the past decade the U.S. has consumed between 20 and 25 Tcf of natural gas a year.

The size of this resource led the U.S. Department of Energy to sponsor test wells into deep brine reservoirs back in the 1970s and 1980s. The wells brought brine to the surface, but producing methane from brine could not compete on price.

Although methane from brine still cannot compete today, the other major benefit—the production of geothermal energy—could change the financial equation. On a human timescale, heat from the earth will last indefinitely. Like other subsurface resources, exploiting it requires injection and extraction wells—all off-the-shelf technology. Geothermal energy from brine is not making greater inroads primarily because the energy density of hot water is about two orders of magnitude smaller than energy obtained by burning the same volume of coal, oil or gas.

That pessimistic assessment relates to using geothermal energy to produce electricity. Yet roughly 10 percent of U.S. energy consumption is for heating and cooling the air in buildings and for heating water in homes, according to a recent DOE-sponsored reevaluation of geothermal energy. A 2,200-degree flame, like the one in a domestic gas-fired hot-water heater, is overkill. Low-intensity geothermal energy can pay if it is used for low-intensity applications such as warm air and hot water; geothermal heat pumps have been doing this successfully for homes in Europe for many years.

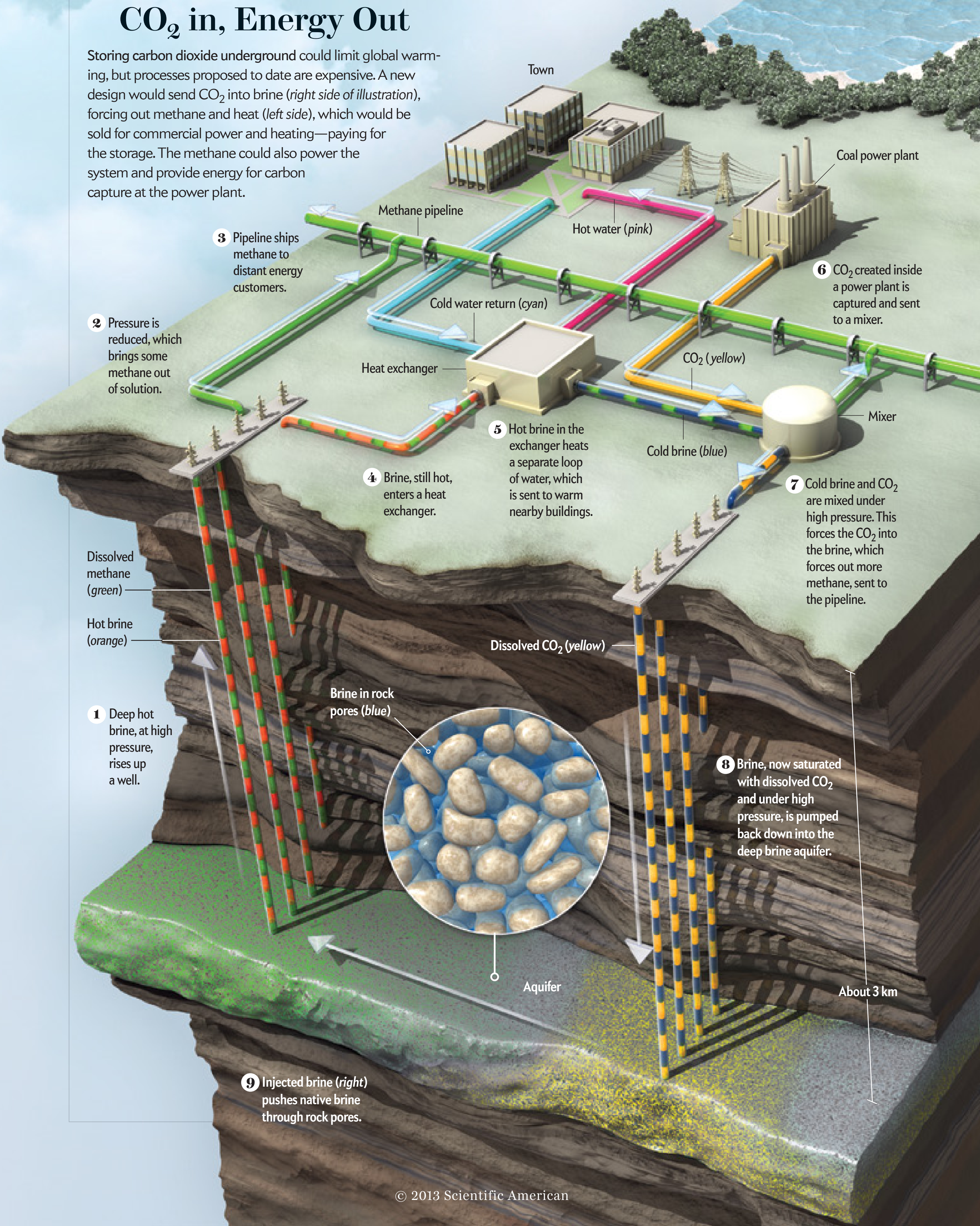
THREE PROCESSES BECOME ONE

NEITHER STORING CO_2 belowground, nor tapping brine for methane fuel, nor drawing up deep brine for geothermal heat is economically viable on its own. But the combination of all three processes into one system starts to look like a three-legged stool: they become self-supporting. The ultimate question, however, is whether the system could sequester enough CO_2 to significantly reduce emissions on a national and international scale.

We recently made some calculations for the Gulf Coast. That area has a large number of fossil-fuel power plants and other industries that generate a lot of CO_2. To make an even larger dent in U.S. emissions, CO_2 could be transported from distant sources. The capital to build pipelines can be considerable, but operating costs are modest, and here again the scale is doable. For example, in the 1980s industry built more than 3,400 kilometers of

CO_2 in, Energy Out

Storing carbon dioxide underground could limit global warming, but processes proposed to date are expensive. A new design would send CO_2 into brine (*right side of illustration*), forcing out methane and heat (*left side*), which would be sold for commercial power and heating—paying for the storage. The methane could also power the system and provide energy for carbon capture at the power plant.



pipelines across four states near the Permian Basin in western Texas to bring CO_2 from natural, underground reservoirs to oil fields, where it is used to enhance oil recovery. The coast has enormous deep brine reservoirs. It has an extensive natural gas pipeline infrastructure that feeds the rest of the country. And it has a large population that could exploit geothermal energy.

Storing one gigaton of CO_2 a year, which is a sixth of the current U.S. emissions rate, would entail injecting and extracting about 400 million barrels of brine a day. That rate is large, but it could be achieved with about 100,000 injector and extractor wells (for reference, more than a million wells have been drilled in Texas for oil and gas). Completion of that many wells would take decades. Yet that time span would be true of any technology that averts one gigaton of CO_2 emissions a year. For example, U.S. emissions could drop that much if 200 gigawatts of electricity now generated by coal plants was instead generated by nuclear power plants. Approximately 200 large reactors would have to be built, which would certainly take decades.

The rate of energy production would also be large enough to pay for the system. Storing one gigaton of CO_2 would produce about 4 Tcf of natural gas a year, about a sixth of current U.S. consumption. The U.S. produced about 9 Tcf of natural gas from shale in 2012, which was worth $25 billion.

The rate of geothermal energy production would be significant, too. If the heat were used to provide hot air and water—and if it were also used in heat exchangers that convert warm air into cold for air conditioning—the energy captured would be about the same as the energy provided by the methane: nearly 200 gigawatts. It is unclear whether that much demand would exist along the Gulf Coast, although the many petrochemical plants there, as well as the many carbon-capture units that would be built, could use a large portion of it. Alternatively, if the thermal energy were converted to electricity with 10 percent efficiency, as is typical elsewhere, then 20 gigawatts of electricity would be produced, which would still be substantial: the U.S. has about 50 gigawatts of wind capacity.

It appears that our system has production rates big enough to support large-scale CO_2 reductions. The volume calculations seem favorable as well. Storing one gigaton of CO_2 a year for a century would sequester 100 gigatons of CO_2. It would also produce 380 Tcf of methane—less than a tenth of the methane estimated to exist in deep aquifers along the Gulf Coast. So there is ample room for storing CO_2 and an ample supply of gas.

If the methane were burned by power plants, even without capturing the CO_2 that the burning would produce, the net drop in CO_2 emissions would be 80 gigatons for a century of operation. That is a substantial drop. For example, the Union of Concerned Scientists has determined that for the world to limit atmospheric CO_2 concentration to 450 parts per million (the level generally cited to keep global temperature rise to less than two degrees Celsius), the U.S. and other industrial countries would have to reduce emissions to roughly 25 percent of 2000 levels by 2050. The U.S. would need to avoid about 150 gigatons of CO_2 between now and 2050. Even if the brine process took 20 years to reach the one-gigaton-a-year level of sequestration, it could account for 15 percent of the required U.S. reduction.

Of course, the wells and the brine-injection plants would have to be built and operated with great care to prevent methane from leaking into the atmosphere as so-called fugitive emissions. The wells would be similar to conventional onshore oil and gas wells—mature technology. The U.S. Environmental Protection Agency has a solid program for detecting emissions and their sources. And industry would not want to lose a valuable product it could sell. Processing the brine, methane and CO_2 would be similar in complexity to operations at petrochemical plants—another mature industry. Finally, because only liquids would be moving in the underground reservoir, drilling and operating the wells would be very much like conventional oil operations that have been practiced for decades. The issues associated with fracking shale—sending chemicals and large volumes of freshwater underground and the safe disposal of chemical-laden fracking fluid—would not arise for this process.

The possibility of inducing seismic activity would be extremely low, too. Recent research shows that adding large volumes of fluid into certain geologic formations—sometimes done to dispose of wastewater—might raise the risk of earthquakes. Yet the brine process is a closed loop; all the brine that gets injected is first extracted from the same formation. In this way, the original, average pressure in the formation is maintained.

Building such a system could be expensive, of course, and could raise electricity costs to consumers. But so would any serious effort that is big enough to make a meaningful difference in CO_2 emissions—whether it is building thousands of solar and wind farms or another 200 nuclear reactors to replace coal-fired power plants. [For more on costs, see More to Explore, below.]

GETTING STARTED

GIVEN OUR MANY CALCULATIONS, the brine-sequestration system seems to work on paper. Yet test plants will be vital in determining whether our system would be practical in the field. Researchers at Sandia National Laboratories, Lawrence Livermore National Laboratory and the University of Edinburgh in Scotland are designing ways to efficiently inject CO_2 into brine and extract energy. And two companies, which wish to remain nameless, are considering whether to build pilot plants along the Gulf Coast.

Gaining experience now would be prudent because if the world has any hope of limiting temperature rise caused by global warming, CO_2 emissions have to be reduced imminently.

The U.S. Gulf Coast is the ideal location to build the brine-sequestration system. The emissions problem is global, however. We do not know where else the process could be applied, but the essential element is brine containing dissolved methane, which can be expected wherever hydrocarbons are found. China and Russia, which have growing CO_2 emissions rates and large basins with oil and gas, could be good places to look first. SA

MORE TO EXPLORE

Eliminating Buoyant Migration of Sequestered CO_2 through Surface Dissolution: Implementation Costs and Technical Challenges. McMillan Burton and Steven L. Bryant in *SPE Reservoir Evaluation & Engineering,* Vol. 12, No. 3, pages 399–407; June 2009.

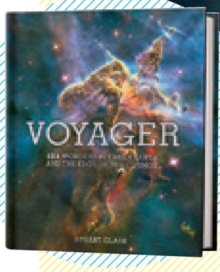
Coupled CO_2 Sequestration and Energy Production from Geopressured-Geothermal Aquifers. Reza Ganjdanesh et al. Presented at the Carbon Management Technology Conference, Orlando, Fla., February 7–9, 2012.

Regional Evaluation of Brine Management for Geologic Carbon Sequestration. Hanna M. Breunig et al. in *International Journal of Greenhouse Gas Control,* Vol. 14, pages 39–48; May 2013.

SCIENTIFIC AMERICAN ONLINE
For more on what the hot-brine system could cost, see **ScientificAmerican.com/nov2013/bryant**

Illustration by Emily Cooper


Cat's Eye Nebula



Voyager: 101 Wonders between Earth and the Edge of the Cosmos

by Stuart Clark. Atlantic Books, 2013 ($35)

Beautiful images abound in books about the depths of space; beautiful words are far more rare. In *Voyager,* Clark, a veteran astronomy journalist, gives us both, explaining the science behind the most gorgeous vistas from space telescopes and interplanetary probes. The odyssey begins on Earth, before leaping out through the solar system, then to nearby stars, finally to surrounding galaxies and the frontiers of existence itself. What look to be bullets piercing bull's-eye targets are in actuality galaxies plowing into one another; star-forming molecular clouds almost seem to be turbulent swirls of cream against a background of dark coffee. Gemstones scattered across black velvet prove to be clusters of galaxies at the opposite end of the cosmos, and a map of the universe's largest structures is the spitting image of microscopic branching neurons. In Clark's capable hands, the wonders of the night sky become delightfully familiar.

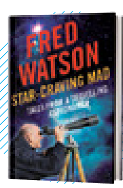
Our Once and Future Planet: Restoring the World in the Climate Change Century

by Paddy Woodworth. University of Chicago Press, 2013 ($35)

For some environmentalists, saving the planet is not just about preserving natural resources; it is also about fixing the disruptions caused by centuries of human activity. The practice, called ecological restoration, is the subject of journalist Woodworth's *Our Once and Future Planet.* Woodworth gives a stirring portrait of the hardworking environmentalists who are trying to restore landscapes to their former, untouched glory, but he also captures the dark side of the enterprise: it sometimes requires the brutal destruction of very large numbers of invasive species to make room for long-departed native ones. Restoration is also basically guesswork, Woodworth notes, because most of us have never actually experienced nature at its most pristine. Ultimately, he ends up wondering whether we can ever hope to restore "degraded ecosystems, and our own damaged relationship to the environment." —*Arielle Duhaime-Ross*

Star-Craving Mad: Tales from a Traveling Astronomer

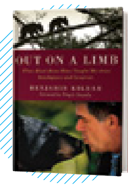
by Fred Watson. Allen & Unwin, 2013 ($16.95)



Armed with dry wit and a dash of whimsy, Australian astronomer Watson makes difficult scientific concepts such as dark energy, the Higgs boson, and the surprisingly hazy distinction between giant planets and small stars seem simple. Whether telling tales of pseudoscientific alien encounters at conferences, journeying to ancient observatories in Peru or relating his views on what differentiates astronomy from all other scientific fields—"since there is no marketable end-product, there is little scope for corruption," he writes—Watson entertains and enlightens. He deftly twists and turns between astronomy history and cutting-edge research, ultimately transforming a book about space science and physics into a rarity: light reading packed with valuable information. —*Arielle Duhaime-Ross*

Out on a Limb: What Black Bears Have Taught Me about Intelligence and Intuition

by Benjamin Kilham. Chelsea Green Publishing, 2013 ($24.95)



Nearly 20 years ago, after dyslexia derailed his hopes for a scientific career, Kilham found another way to perform research, rearing and closely observing orphaned black bear cubs on his New Hampshire farm. He had "no reputation to worry about," no hypothesis to prove; he simply raised cubs and watched over them through their reintroduction to the wild. As detailed in this book, his work led him to discover a previously overlooked scent receptor on the roof of each black bear's mouth (which he coined a "Kilham organ") and to challenge the common view of bears as solitary, unsophisticated creatures. In the tradition of Jane Goodall's chimp studies, Kilham's analyses suggest that bears are capable of surprising altruism and cooperation and perhaps even long-term planning and symbolic thought. *Out on a Limb* reveals not only the inner lives of bears in poignant detail but also Kilham's deep, abiding respect and love for these sometimes savage, often gentle beasts.

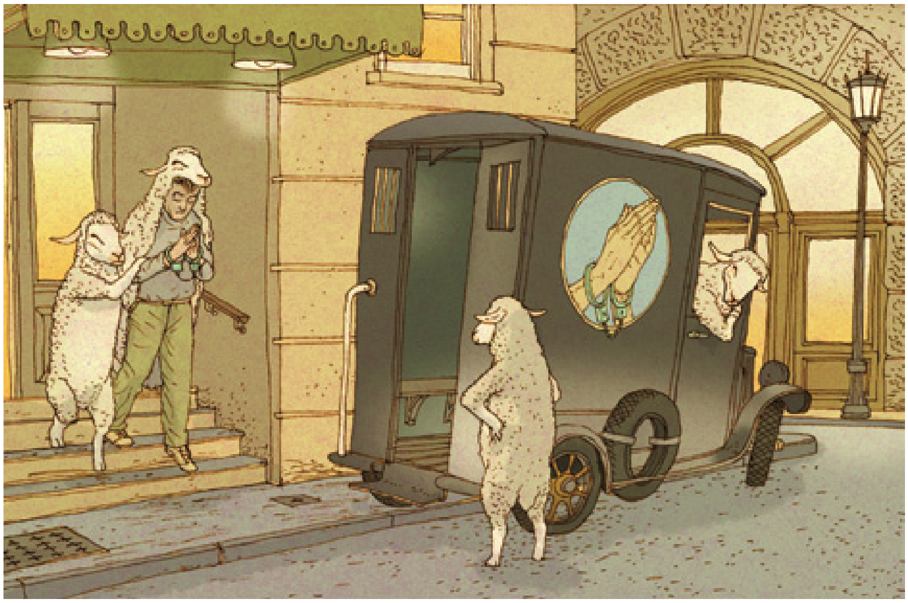
SCIENTIFIC AMERICAN ONLINE
For more recommendations, go to ScientificAmerican.com/nov2013/recommended

COURTESY OF NASA/ESA/HEIC/HUBBLE HERITAGE TEAM

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His book *The Believing Brain* is now out in paperback. Follow him on Twitter @michaelshermer

Sovereign Insanity

How weird beliefs can land you in jail



When I was in college, my friend and I attended a tax seminar in which we were told that paying taxes was unnecessary because the Sixteenth Amendment—empowering Congress to levy an income tax—was never legally ratified. After a long and detailed history of the IRS, we were advised not to file a tax return and given instructions on what to do and say when the feds come a-knockin'. The slick presentation seemed internally coherent and logically plausible in the room, but later, after some reflection, I figured it couldn't possibly be true because no one would pay taxes if it were. In contrast, my friend went for it and got away tax-free for years, until the IRS caught up with him and he got his comeuppance.

I was thinking about this incident in August, when I appeared as an expert witness on the psychology of why people fall for such schemes in a Portland, Ore., court in the case of *USA v. Miles J. Julison,* a house flipper who neared financial ruin after the housing-market meltdown. That year he reported $583,151 in "other income" to the IRS on his tax return, claiming that the entire amount was withheld as income taxes. Submitting eight IRS 1099-OID (Original Issue Discount) forms, Julison requested a refund of $411,773. (According to the IRS, an "OID is a form of interest. It is the excess of a debt instrument's stated redemption price at maturity over its issue price.") The IRS sent him a check in that amount, which he spent on a home loan, personal debts, a car and a boat. Emboldened by his success, the next year he demanded a refund of more than $1.5 million. This time, however, instead of a refund check he got a trip to court and, after a guilty verdict, jail.

This particular tax scam is popular among tax resisters with a conspiratorial bent, especially those who call themselves sovereign citizens, who hold that the U.S. government is actually a corporation, not a country, and that there is a secret account bearing, say, $1 million for every child born in the U.S. Sovereign citizens believe that this money should be "redeemed" to them and that the 1099-OID is one tool among several to get it. Sovereign citizens believe that they are not subject to federal jurisdiction, do not recognize government currency (gold is popular among such far-right groups) and, of course, that taxation is illegitimate. The FBI labels them a domestic terrorist threat, and the Southern Poverty Law Center estimates there are about 100,000 "hard-core sovereign believers."

As a self-proclaimed sovereign citizen, Julison did not recognize the court's right to try him and refused to work with his court-appointed lawyer, who urged him repeatedly to plead guilty for a reduced sentence in the face of overwhelming evidence against him. Instead, as it shows in court records, he kept repeating variants on "I, Miles Joseph, a bond servant of Jesus Christ, can only take an oath to Jesus Christ, as he has bought and paid for me by the blood of the lamb. And anything else, any other oath would violate the religious dictates of my conscience. And I continue to reserve all of my rights without prejudice."

During a lunch break, when we were alone, I asked Julison if he really believes all these sovereign citizen claims or if he was just in it for the money. "The United States is a corporation in the state of Delaware. I have their registration papers printed right off their Web site. Before anything can be argued, there has to be a jurisdiction established," he responded. "So my description of you as a true believer is true?" I queried. "I believe in the blood of the lamb," he responded biblically.

A number of social and psychological factors are at work in the creation of a true believer, most notably the authority of a leader, the influence of others engaged in the scheme and especially the reinforcement by the government itself in the form of a refund check. The take-home lesson is that if it sounds too good to be true … leave it off your tax return. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2013

Illustration by Izhar Cohen

The ongoing search for fundamental farces

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.

Saturnalia

Seeing Saturn through a telescope can leave a ringing in one's ears

I ran into Ira Flatow early one February morning in 1997 in Seattle. We were about to enter the venue of the Annual Meeting of the American Association for the Advancement of Science for a day of lectures. The host of NPR's immensely popular *Science Friday* eyeballed me. "You don't look so good," he said, observing my greenish hue. "I don't feel so good," I muttered before deciding to retreat from the retreat and return to my hotel room. That night I wound up in a hospital emergency room with gastroenteritis so severe that when the doctor lightly palpated my tummy I spewed, the last of many such upchucks that day.

My encounter with Flatow left me with an unshakable faith in his ability to communicate science. "You don't look so good." Simple and accurate.

And so I sat in rapt attention on August 7 of this year when Flatow joined *Scientific American* editor in chief Mariette DiChristina for a conversation entitled "Teachable Moments with Science in Culture" at the Learning in the Digital Age summit, sponsored by this magazine and its parent company Macmillan Science and Education. Flatow told DiChristina about a teachable moment at his own home.

"Being a science geek myself," he began, "I'm always interested in astronomy. And I was out with my backyard telescope. This is a few years ago. And my daughter was 14. If you have a 14-year-old, you'll know exactly what I'm talking about. And the rings of Saturn were just beautiful that night—you could see it great. And I kept begging her to come out and look at this. And she said, 'Oh, Daddy, don't do this, c'mon, I don't wanna go see it, you're such a nerd.' I literally grabbed her hand, I pulled her. 'No, I don't wanna see it! I don't wanna!' I took her head, and I shoved it to the eyepiece, and she goes, 'Holy sh–t!'"

Flatow's story of the jaw-dropping (and occasionally profanity-inducing) effect of seeing Saturn's rings reminded me of my own telescopic encounter with the gas giant, about a decade ago.

I was at the beachfront apartment of friends in south Florida. The place had a balcony, and the balcony had a telescope. The scope was nothing fancy, the kind of simple refractor that today would cost about $100. A thick layer of dust indicated that nobody had looked through the thing in a long time. While the rest of the assembled schmoozed in the living room, I started fooling around with the telescope.

I know baseball stats better than I recognize features of the night sky, but by naked eye I can usually distinguish the twinkling pinpoint light of a star from the steady glow of a planet's disk. And off in the northeast sky that night was what looked like a disk. So I trained the telescope on the presumed planet and focused it up. I either said, "Wow," or something more like what the younger Flatow uttered.

I went back inside and asked the owner of the telescope if he'd ever seen Saturn. He had not. He followed me onto the balcony, looked into the eyepiece, and saw the planet and its famous rings. His head jerked back. "Did you do something?" he asked me. I didn't even know what he meant. He spun the telescope around and examined the objective lens. "What are you doing?" I asked. He said, "You drew something on it."

Once I stopped laughing, I showed him there was no image of Saturn unless the telescope was actually pointing at Saturn.

Both Flatow the younger and my Florida friend had no doubt seen photos of the planet, with more clarity and detail. But a glimpse of those rings with nothing between them and you but a magnifying lens is somehow different.

A scientist doing original research on rare occasions gets to be the first person in the world to find something or to know something. We science appreciators can get a taste of that thrill virtually on demand. Just grab a book, a rock hammer, a magnifying glass, a cheap telescope. You will not be Saturn's discoverer. But you may still be amazed when you discover Saturn for yourself. SA

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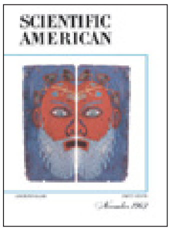
Illustration by Matt Collins

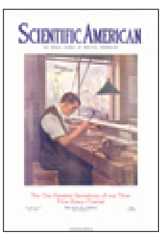


November 1963

Vision in the Brain

"In most parts of the nervous system the anatomy is too intricate to reveal much about function. One way to circumvent this difficulty is to record impulses with microelectrodes in anesthetized animals, first from the fibers coming into a structure of neurons and then from the neurons themselves or from the fibers they send onward. Comparison of the behavior of incoming and outgoing fibers provides a basis for learning what the structure does. Through such exploration of the different parts of the brain concerned with vision one can hope to build up some idea of how the entire visual system works. That is what Wiesel and I have undertaken, mainly through studies of the visual system of the cat. —David H. Hubel"

Hubel and Torsten Wiesel had a share of the 1981 Nobel Prize in medicine for this work.



SCIENTIFIC AMERICAN, VOL. CIX, NO. 18; NOVEMBER 1, 1913

November 1913

Ten Greatest Inventions, 1888–1913

(*Scientific American* ran an essay contest on the "ten greatest inventions of our time," defined as the 25 years prior to 1913.)

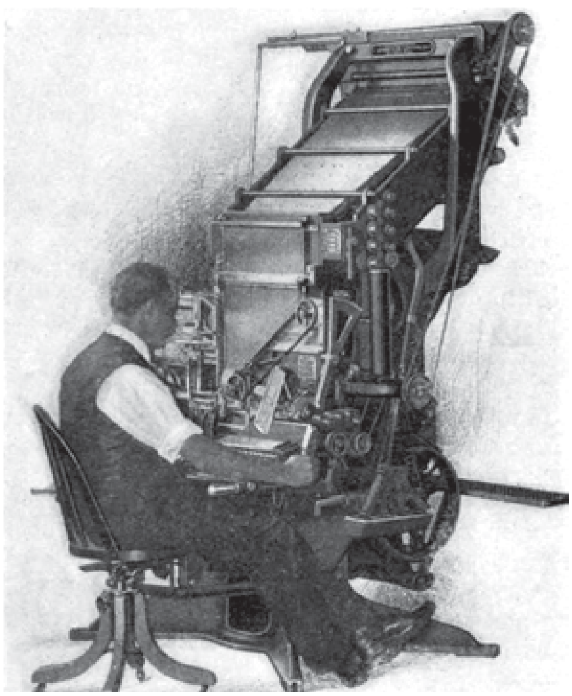
"No two competitors selected the same set of inventions. In fact, only one invention, that of Wireless Telegraphy, was conceded unanimously to belong among the ten greatest. The vote on Aeroplanes was almost unanimous. But beyond that there was not the slightest trace of unanimity. The following is the result of the vote on a percentage basis:

Wireless telegraphy—97%
Aeroplane—75%
X-Ray machine—74%
Automobile—66%
Motion pictures—63%
Reinforced concrete—37%
Phonograph—37%
Incandescent electric lamp—35%
Steam turbine—34%
Electric car—34%"

The Linotype composition machine ranked 20th [see illustration]. *For the rest of this list and excerpts from the prizewinning essays, see www.ScientificAmerican.com/nov2013/inventions*

Darwinism and Wallaceism

"Alfred Russel Wallace has just passed away. In a letter to Joseph Hooker written in 1858, [Thomas Henry] Huxley writes, 'Wallace's impetus seems to have set Darwin going in earnest, and I am rejoiced to hear we shall learn his views at last. I look forward to a great revolution being effected.' The communication from Wallace did certainly serve to accelerate Darwin's work; but it would be a serious mistake to suppose that the service of Wallace was confined to stimulating Darwin. There can be no doubt that if Darwin had not given to the world the theory of natural selection, Wallace would have done so."



COMPOSITION: The latest version of the Mergenthaler machine for setting type in 1913. It ranked "with the invention of movable type and of the printing press."

November 1863

Petroleum Trade

"In carrying petroleum from one place to another, or when it is lying in stores or sheds, some of the liquid will convert into vapor, in which state it will escape through very minute openings or pores in the vessel containing it. A loss of the liquid is not only thus caused, but this vapor when it escapes and mingles with about eight times its volume of air, becomes as explosive as gunpowder, and if the light of a match or lamp is then brought into contact with it, a violent explosion will take place. Several sloops loaded with petroleum have been subjected to explosions, and an accident of a similar kind recently took place in a large druggist's establishment in Albany, N.Y. Cases like these call for preventive agencies, such as vessels that will not leak, and special places for storage."

Now Read This

"Don't take a newspaper; don't read one of any kind. If you hear persons discussing this or that great battle, ask stupidly what it all means. Emulate Rip Van Winkle; steep your senses in moral and mental oblivion, and pay no attention to what is passing about you. If you have children, don't take any paper for them; tell them 'book larnin' ain't no 'count.' In this way you may save two or three dollars—the price of a paper—and lose $500 or $5,000 by not being informed about markets, supply and demand, and a thousand other things as essential to an enterprising man as light and air."

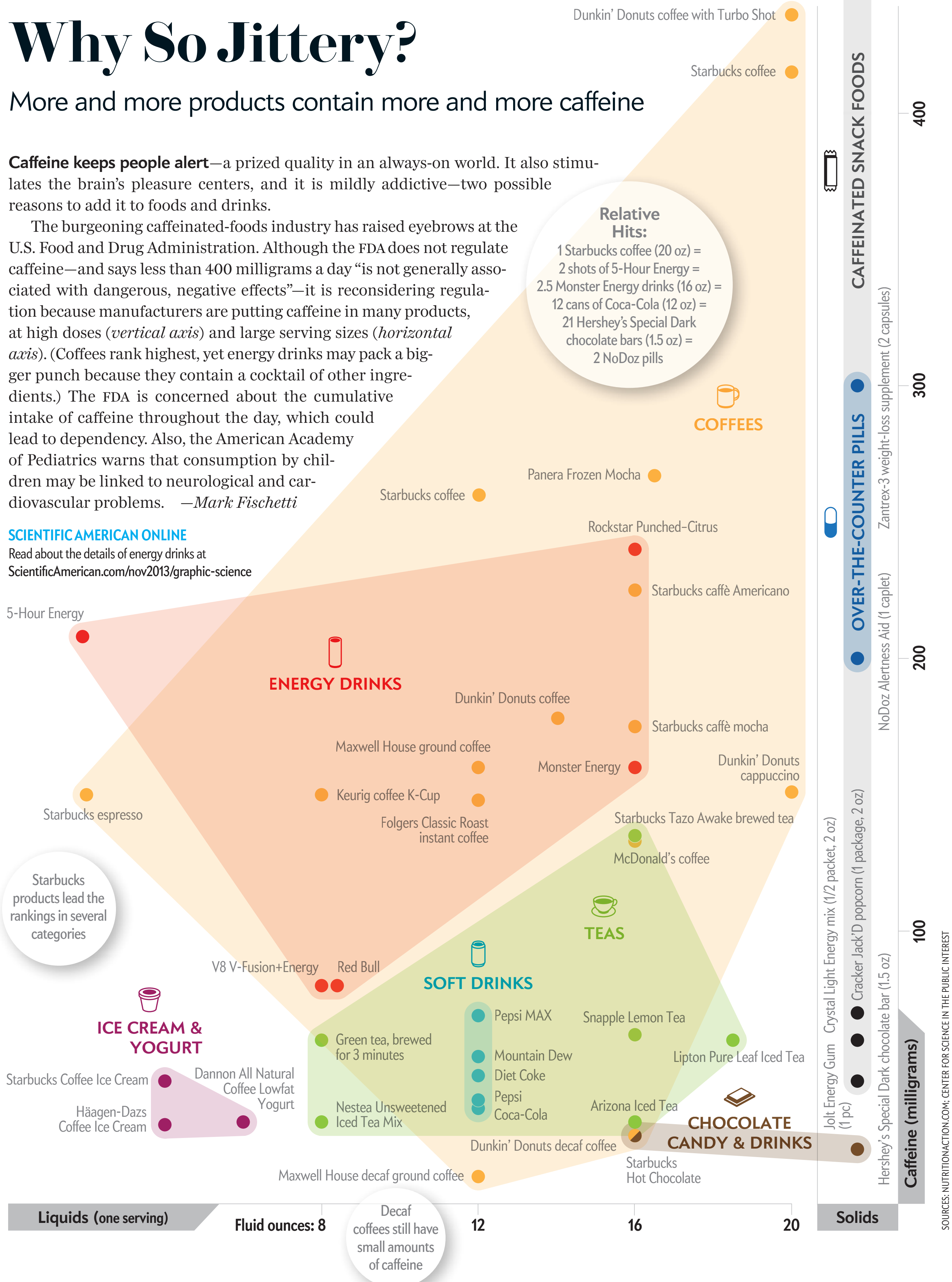
Why So Jittery?

More and more products contain more and more caffeine

Caffeine keeps people alert—a prized quality in an always-on world. It also stimulates the brain's pleasure centers, and it is mildly addictive—two possible reasons to add it to foods and drinks.

The burgeoning caffeinated-foods industry has raised eyebrows at the U.S. Food and Drug Administration. Although the FDA does not regulate caffeine—and says less than 400 milligrams a day "is not generally associated with dangerous, negative effects"—it is reconsidering regulation because manufacturers are putting caffeine in many products, at high doses (*vertical axis*) and large serving sizes (*horizontal axis*). (Coffees rank highest, yet energy drinks may pack a bigger punch because they contain a cocktail of other ingredients.) The FDA is concerned about the cumulative intake of caffeine throughout the day, which could lead to dependency. Also, the American Academy of Pediatrics warns that consumption by children may be linked to neurological and cardiovascular problems. *—Mark Fischetti*

SCIENTIFIC AMERICAN ONLINE
Read about the details of energy drinks at ScientificAmerican.com/nov2013/graphic-science



Graphic by Golden Section Graphics

You can comparison shop most services. Why not health care?

▶ SIMPLICITY Before you hire someone to paint your house, you shop around to see who does good work and get estimates. But it doesn't usually work that way with health care. At UnitedHealthcare, we provide members with an easy to use tool that helps you get information on quality rated doctors, treatment options and estimates for how much you'll pay. So you can make better care decisions. You don't want guesswork, especially when it comes to your health. Innovations that work for you, that's **HEALTH IN NUMBERS℠.**

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