ASTROPHYSICS
Hunting Neutrinos in Supernovae

PSYCHOLOGY
Google Is Changing Your Brain

INFECTIOUS DISEASE
Health Threats from Fungi

SCIENTIFIC AMERICAN

ScientificAmerican.com

DECEMBER 2013

WORLD CHANGING IDEAS

The New Alchemists

How supercomputers are transforming innovation in materials design

Weather

Speaker: Robert G. Fovell, Ph.D.

How and Why Clouds Form

Clouds are key in the planetary energy balance and water cycle. Historically, they have signaled atmospheric processes to observers. Learn about clouds' characteristics, formation, and function, with details on precipitation, ice, and lightning. We'll look at clouds from all sides, identifying the many ways clouds are essential to Earth and the atmosphere.

How and Why the Winds Blow

Delve into the role, causes and features of this invisible phenomenon. We'll look at the basics of atmospheric circulation and the complex interactions within the atmosphere that create wind. Learn about local winds (sea breezes), large-scale ones (fronts and cyclones) and legendary severe winds associated with mountains. Hone your knowledge of wind and its impacts.

Severe Storms

Storms impact our wellbeing, homes, cities, and economies. Learn about the causes, formation, and lifecycle of severe storms. Look at supercell thunderstorms and tornadoes, and the role of moisture and vertical wind shear in storms. From squall-lines, bow echoes, and flash flooding to hurricanes, get the latest need-to-know information on these forces of nature.

Understanding Extreme Weather

Synthesizing our knowledge from the three previous sessions, we'll apply these concepts to examples of extreme weather events from the recent past: 2013's devastating Colorado floods. The 2013 Oklahoma tornadoes. 2012's Hurricane Sandy. 1993's epic East Coast Snowstorm. 1991's "Perfect Storm."

Particle Physics

Speaker: James Gillies, Ph.D.

Hunting the Higgs Boson

Particle physics is the study of the smallest indivisible pieces of matter and the forces that act between them. Learn about the particle accelerators, detectors and computing that make this research possible at the Large Hadron Collider, and how hundreds of physicists teamed to hunt the long-sought Higgs boson.

Life after Higgs: What's Next?

Physicists at the Large Hadron Collider announced in 2012 they'd found *a* Higgs boson. But not *the* Higgs boson. What's the difference? Learn what the particular properties of the recently discovered particle could tell us about the nature of the universe, and why physicists don't know yet which Higgs boson they've found.

60 Years of Science for Peace

Sixty years ago, the idea of CERN, the European particle physics laboratory, was born. Hear the interwoven scientific and political stories of CERN's development and how particle physics has evolved from a regional to a global field, with the Large Hadron Collider as its frontier research tool.

Celebrating 25 years of the World Wide Web

"Vague, but exciting," were the words scrawled on Tim Berners-Lee's 1989 proposal for what became the World Wide Web. Hear the story of the Web's birth based on archival material and interviews with the major players, and learn how developments in physics and computing paralleled the development of the Web itself.

Planets

Speaker: David Stevenson, Ph.D.

Planetary Diversity

The Kepler spacecraft has found hundreds of planets and thousands of additional candidates. Exploration of our solar system leads to a view of planets that emphasizes diversity rather than similarity. With so many planets out there, yes, some must be like Earth, but are the most exciting prospects for planets and life forms very different from our home? Absorb the possibilities.

Origin of Earth & Moon

Four and a half billion years ago our own solar system developed from a disk of gas and dust. Get our current understanding of this process and how Earth emerged with the Moon, an atmosphere, oceans, a magnetic field, and conditions for life. Explore how the nature of Earth is inextricably linked to the existence of our satellite companion.

Ice Worlds

There is more ice and liquid than rock in our solar system, including some exotic stuff: hot, dense soups of protons and oxygen ions deep under planetary surfaces; rivers and lakes of liquid hydrocarbons, and ice geysers. Find out the details as we explore the structure and dynamics of the large satellites and Pluto.

Jupiter!

Our solar system's largest planet, Jupiter, likely influenced Earth's formation and so is a key to understanding Earth. Delve into Jupiter's internal properties and interior structure, and family of satellites. Get an insider's scoop on the billion dollar Juno mission arriving at Jupiter in July 2016 and learn about Dr. Stevenson's Juno role studying Jupiter's gravity and magnetic fields.

Working in Space

Speaker: Rhea Seddon, M.D.

Gravity and You: Research in Space

Learn about space research from the perspective of an astronaut who flew on the first two Space Shuttle missions dedicated entirely to life sciences experiments. Through stories and video of her missions, Dr. Seddon will explain how she served as both subject and operator for experiments, and what microgravity research has taught us.

Astronaut Training Explained

Learn about NASA astronaut training from someone who went through it. Dr. Seddon will share her first-hand perspective on how a non-aviator trains for flight in high performance jets, floats weightless in the aircraft known as the "Vomit Comet," and uses simulators to practice every aspect of flight before ever reaching orbit.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS TOUR OF THE MUSEUM OF FLIGHT & BOEING

Pre-Cruise Full-Day Tour, Aug. 23rd.

If you love vapor trails in the wild blue yonder and the thrill of takeoff, indulge in a day at the Future of Flight Aviation Center & Boeing Tour in Everett, Washington *and* the Museum of Flight at legendary Boeing Field, Seattle.

Take a 90-minute tour of Boeing's plant, getting a bird's-eye view of the new 787 Dreamliner being assembled. Get the big picture of aviation in the the Museum of Flight, from biplanes to jets. Please join us!

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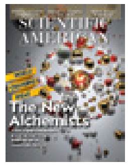
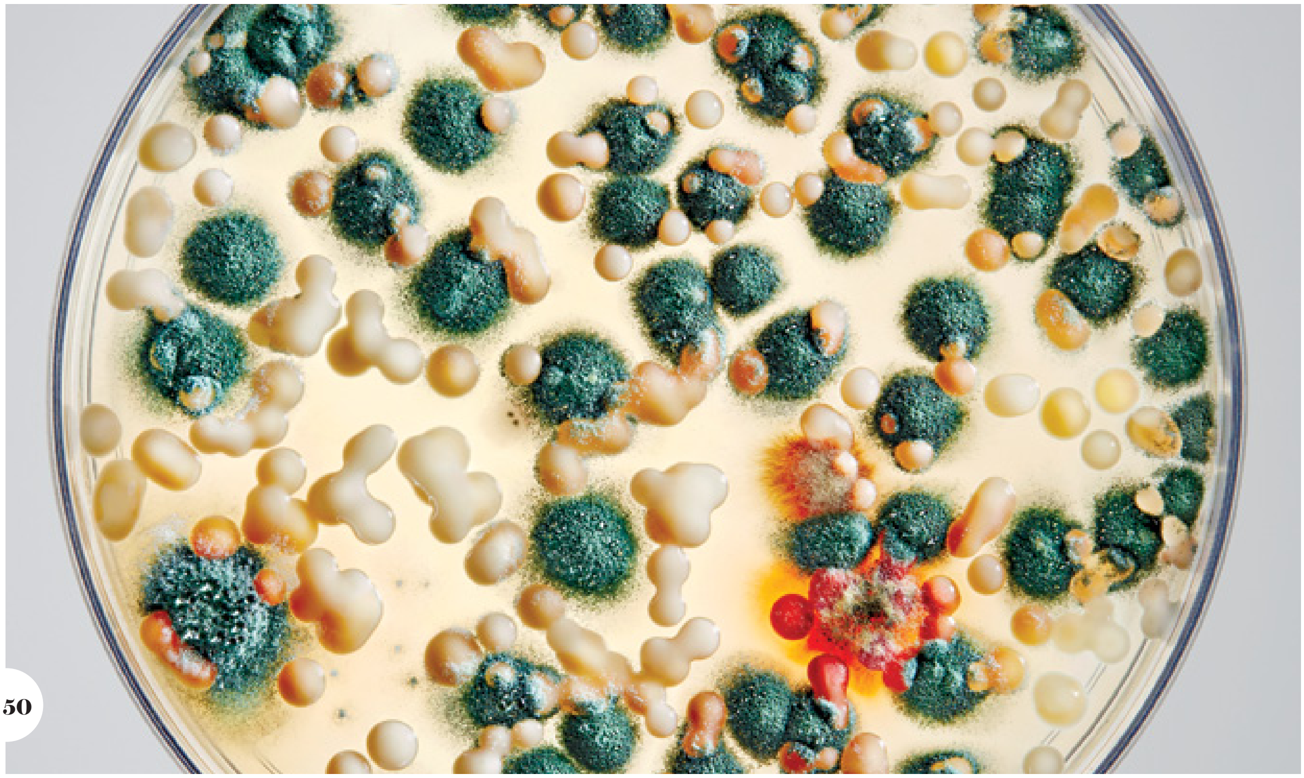
SCIENTIFIC AMERICAN

December 2013 Volume 309, Number 6

ON THE COVER



Inventing new materials has always involved a huge amount of trial and error. Now, by feeding the equations of quantum mechanics into supercomputers, scientists are reinventing the way materials are designed. Their process is one of the 10 revolutionary advances featured in our fifth annual "World Changing Ideas" special report. Image by André Kutscherauer.



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FEATURES

Photograph by Zachary Zavislak

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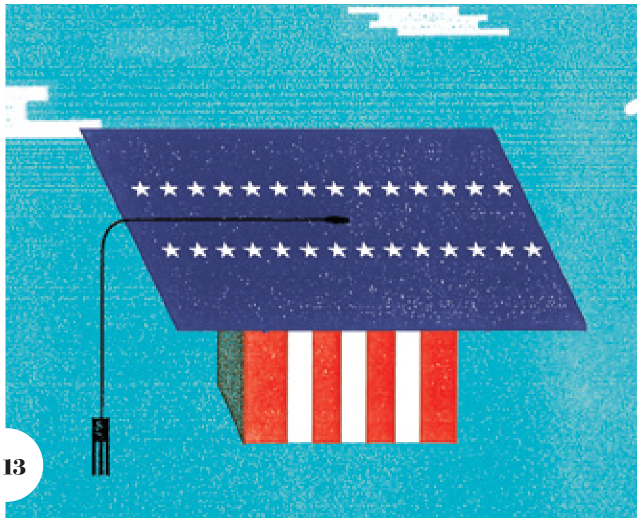
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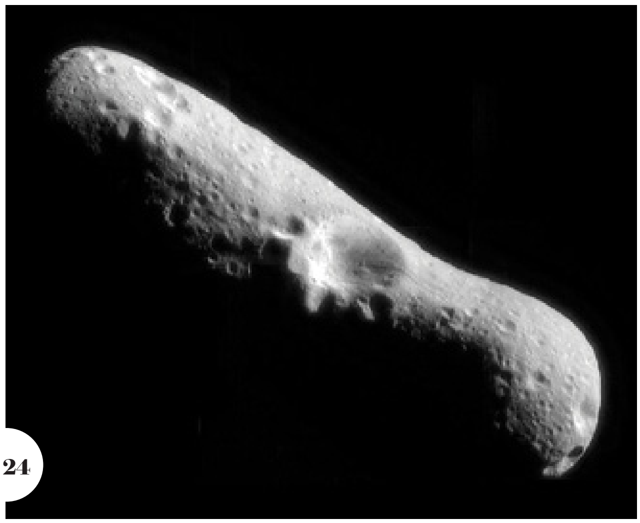
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DEPARTMENTS

ON THE WEB

Fighting the Flu
As flu season nears its peak, we take a look at how doctors and scientists are racing to get the upper hand on the dangerous—and unpredictable—family of influenza viruses.
Go to www.ScientificAmerican.com/dec2013/flu

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

One Atom at a Time

I HAVE ALWAYS HAD A SOFT SPOT FOR THE philosophical dreamers among us, and the ancient alchemists are no exception. Maybe it is partly because, in eighth grade, I was a serious little person with a 100 average in my science class and a very proud member of an after-school club called the Alchemists. (Our main function seemed to be to bring order to the Bunsen burners and various flasks.) But I think, beyond that, I have always admired the raw ambition of trying to transform something that has little value (such as base metals) into something that has a great deal (such as silver and gold).

ALCHEMICAL SYMBOLS from Goosen van Vreeswijk's *Het Cabinet der Mineralen,* 1670.

Of course, the process of science is the major tool today for shaping the world in material ways that help to improve human lives. And with an increasingly crowded, warming world, we are far less interested these days in transforming dross into precious metals than we are in developing solutions that allow us to create a sustainable future.

In this issue's cover story, "The Stuff of Dreams," on page 36, Gerbrand Cedar and Kristin Persson describe a modern take on alchemylike conjuring: the ability, as our authors explain it, to "design new materials from scratch using supercomputers and first-principle physics." Manufacturers of cars, planes and other such equipment have been designing virtually for many years, they write. Now materials scientists are joining them, working at the level of quantum mechanics.

That feature article is part of our annual report on "World Changing Ideas," starting on page 34. We debuted this special section several years ago to recognize innovation that is ready to spring from the labs in a practical, significant way. Among this year's thought-provoking notions we offer "soft" robots, flexible smartphones, ways to treat illnesses by manipulating the genes in our gut microbes, toolbox-size labs to detect bad medicines, and snap-together bridges and planes.

Control over our world is hardly firm, of course. In fact, as you will see in "How Google Is Changing Your Brain," by Daniel M. Wegner and Adrian F. Ward, our own technologies are molding us in turn. In their article, which begins on page 58, you will learn how our increasing reliance on tools such as Internet search engines is actually diminishing our powers of recollection. At a recent corporate dinner, I saw it in evidence. Someone asked, "Who said, 'Absolute power corrupts absolutely'?" I shouted the answer. After a pause, several people whipped out smartphones to check because nobody else could remember. If you can't either, now you can always look it up. SA

GETTY IMAGES

Illustration by Nick Higgins


BUTTON
LOOK, NO VACUUM PUMP!
New Rabbit®
Electric Wine Preserver
Now you can preserve red wine at the touch of a button—and no need for a vacuum pump. Simply insert a Wine Preserver Stopper into the top of the bottle you want to preserve. Then place the Rabbit Electric Wine Preserver over the Stopper and press the button on top.
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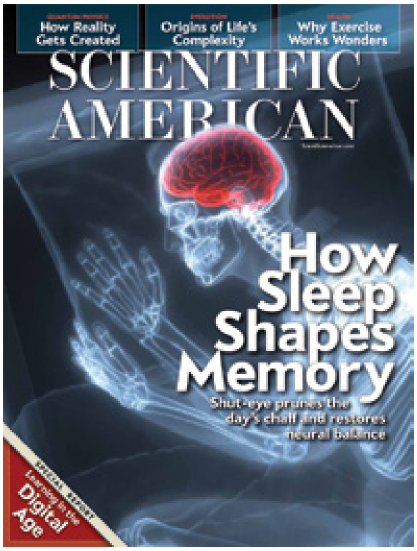

August 2013

QUANTUM REALITY

As Meinard Kuhlmann points out in "What Is Real?" particles and fields are not real but are analogies developed to describe another realm of reality, one that is not accessible to our senses but inferred from observation, measurement, mathematics and theory. An electromagnetic wave is not really like a wave on the ocean, but it is in many ways analogous to such a wave, and through such an analogy, it seems more comprehensible. We must remember that such representations do not describe the true, alien reality of the quantum-mechanical world. We are like fish studying the stars.

JOHN BALL
Huntsville, Ala.

"We must remember that representations do not describe the true, alien reality of the quantum-mechanical world. We are like fish studying the stars."

JOHN BALL *HUNTSVILLE, ALA.*

DIGITAL EDUCATION

The articles in the special report Learning in the Digital Age neglect two crucial aspects of teaching. The first is motivation. The digital-learning methods espoused by many of the articles may work well for the highly motivated students highlighted, but most of their peers are not well motivated.

When I read that massive open online courses (MOOCs) and other computer-based learning systems rely on lectures by "good" teachers, I wonder if the definition of "good" is producing students who score well on standardized tests. Good teachers first motivate their students, and motivation does not come from a computer screen but from when students see their instructors deeply involved in learning.

The second aspect is developing critical thinking skills. A few years after I began teaching a general education science course, it became obvious my students weren't learning anything from a template of information-based lectures and multiple-choice tests. I changed my testing format to essay-type questions that required understanding and instituted an optional "review" session outside of regular class hours, which was two hours of intensive interaction with my students, designed to help develop their critical thinking skills. Almost every student dramatically improved in this area by the semester's end.

The facts and knowledge learned in any course will become obsolete well before you retire. The ability to think critically is a skill that will last a lifetime.

KENNETH C. YOUNG
Retired associate professor
University of Arizona

As a high school student, I am excited by the great potential of personalized education technology as described in "Machine Learning," by Seth Fletcher, but a couple of things concern me.

First, in my experience, school boards aren't very good at choosing effective technologies, and students are often forced to use frustrating and buggy applications. Second, I fear adaptive software would force all students to plod through poorly executed videos and explanations. The promise of "adaptivity" is that every student could work at her or his own pace. I have doubts, however, that educational companies would make effectively different sets of material for students of different ability levels instead of providing the same one-size-fits-all content in a more high-tech, high-cost format.

KAYLENE STOCKING
Seattle

ANALYZING TERRORISM

In "Five Myths of Terrorism" [Skeptic], Michael Shermer claims that the ideas that terrorism is deadly and that "it works" are a "fiction." Shermer expresses a lack of concern over a mere 33 deaths since 9/11 (conveniently subtracting the thousands on 9/11). But how many is too many? Maybe one if you knew and loved that person.

As to terrorism's efficacy: two close friends of mine are suffering from serious leg injuries, and one is now a double amputee because of the recent act of terrorism cited by Shermer. These young, innocent people are only at the beginning of a lifelong physical and emotional struggle. It worked, my skeptical friend.

LORI E. HURLEY
South Hampton, N.H.

I suggest terrorism does work. It has spawned a governmental department that employs tens of thousands of people with a budget of almost $7.7 billion to screen airline passengers. More than a million people stand in line every day and have to take off their shoes prior to being able to board an airplane, with hundreds of thousands of hours of otherwise productive time lost daily because of terrorism. Global terrorists have created a situation that seriously impacts our economic and productive environment.

GARY MORRISON
San Antonio, Tex.

SHERMER REPLIES: Hurley's understandable response illustrates the difference between anecdotal and statistical analysis. Anecdotally, of course, even one death from terrorism is a tragedy to the victim's family and friends, and outrage is an appropriate response. My analysis was on a statistical level in which the numbers of people who have died from terrorism are far below dozens of common causes of death that we have grown accustomed to (such as automobile accidents).

Morrison's observation is well made, but my larger point in showing the failures *of terrorists to achieve their political objectives is that we do not need to invest such time and resources combating terrorism.*

MERITS OF MEMORIZATION

In "The Last Thing You'll Memorize" [TechnoFiles], David Pogue argues that technology has made memorization obsolete.

Having access to information is not the same as knowing it. We learn big things by dividing them into chunks. Some parents think it's easier for kids to learn American history if they organize it around the list of presidents (whose memorization Pogue dismisses). Anyone who can't name a majority of the presidents in approximate order usually knows little about the rest of American history. Joshua Foer describes the right way to memorize in *Moonwalking with Einstein* (reviewed in the March/April 2011 *Scientific American Mind*).

R. C. Mark
Athens, Ohio

DON'T TAKE A SEAT?

"Why Exercise Works Magic," by Shari S. Bassuk, Timothy S. Church and JoAnn E. Manson, stopped short of adding to the recent bad news that high-intensity workouts don't make up for six hours of sitting. If the authors can't explain the mechanism, could they please at least return to your pages with a verdict on what lying down does? Could my seven hours in bed at night be as bad as my hours before a computer screen?

James Guest
East Melbourne, Australia

THE AUTHORS REPLY: Sleeping and sitting are very different. Sleep restores brain function and helps to regulate the body's energy balance. Well-designed bed-rest studies, however, suggest that once the need for sleep is met, lying around all day has similar adverse health effects to sitting—especially if accompanied by snacking.

CLARIFICATION

In "Promise and Peril" [Learning in the Digital Age], Diane Ravitch meant to note that hundreds of thousands, perhaps millions, of teachers regularly use the Internet to exchange ideas about enlivening classrooms. The printed article put the number at "thousands."

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/dec2013

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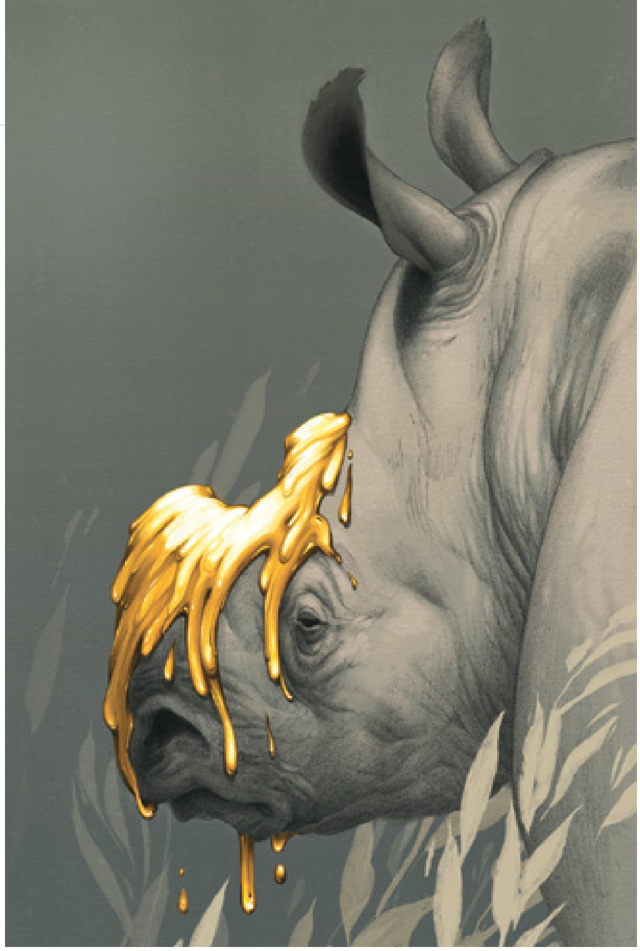

Terrorism's Red Gold

Profits from the illegal wildlife trade now fund terror organizations. The U.S. must do more to stop the poaching

Every day the forest elephants convened at Dzanga Bai to drink the mineral-rich waters. Their gathering in this clearing—located in a UNESCO World Heritage site in the Central African Republic—was so reliable that researchers and tourists flocked there for guaranteed sightings of these elusive cousins of the larger savanna elephants. Then, on May 6, poachers from Sudan arrived. They gunned down at least 26 of the animals, hacked off their valuable tusks and left the bodies to rot.

Such events, often carried out by heavily armed militias equipped with helicopters and night-vision goggles, are becoming increasingly common across sub-Saharan Africa. Transnational criminal syndicates run these operations. Profits are high: a kilogram of elephant ivory can fetch $2,000 on the black market; the same amount of rhinoceros horn can command $65,000—more than cocaine or platinum. All told, illegal wildlife trafficking is an estimated $19-billion-a-year industry, which makes it the fourth most lucrative illicit activity in the world after the drug trade, counterfeiting and human trafficking.

That money is bankrolling extremists, terrorists and other criminal groups around the globe. The Somali militant Islamist group and al Qaeda affiliate al Shabaab—which claimed responsibility for the September terrorist attack at the Westgate Mall in Nairobi—generates up to 40 percent of its funding from illegal ivory, according to a 2012 report from the Elephant Action League, an advocacy group based in Los Angeles. Other al Qaeda affiliates, as well as rebel groups such as the Lord's Resistance Army in Uganda, are also said to run on profits from illegal wildlife trafficking. As a result, elephant and rhino poaching has surged to record levels.

The U.S. is taking notice. In July it established a presidential task force on wildlife crime and pledged $10 million in training and technical assistance to combat poaching in Africa. Yet some U.S. policies continue to contribute to the trade. They must end.

The U.S. is the second-largest market for ivory, among other illegal wildlife products, thanks in part to legal loopholes that allow the trade of ivory depending on how old it is and what kind of elephant it comes from. Because it is practically impossible to distinguish old ivory from new and African ivory from Asian, however, criminals can exploit the legal market to launder illegal ivory. The U.S. should ban the trade of all ivory.

It should also stop issuing import permits for hunting trophies of imperiled species. In March the U.S. Fish and Wildlife Service allowed a wealthy American businessman to import a black rhino that he had hunted for sport in Namibia in 2009—the first such permit in 33 years. Black rhinos are critically endangered, with fewer than 5,000 left in the wild. By giving such permits, the U.S. props up rhino horn as a status symbol.

In addition, we need to leverage our investment power abroad. The U.S. should preferentially give foreign aid to those countries that have demonstrated a commitment to protecting wildlife.

Ultimately combating the trade will take equipment and highly trained wildlife rangers, customs officers and investigators, and those resources require money. The U.S. must give far more aid than the $10 million the Obama administration committed in July or even the $80 million a partnership under the Clinton Global Initiative promised in September. Zimbabwe alone recently said it would need a minimum of $40 million to protect its own wildlife.

Most important, the U.S. must endeavor to eliminate the soaring demand for illegal wildlife from Asian consumers, particularly China's burgeoning middle class. We need to work with China and other countries to educate the public: many Chinese buyers think elephants shed their tusks naturally; Vietnamese buyers think rhino horn cures hangovers and cancer. And if necessary, we should shame these countries and institute trade sanctions until they curb consumption. To be sure, these are drastic measures. But we find ourselves in truly desperate times. The fate of these threatened species is tied to our own. SA

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Illustration by Ashley Mackenzie

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:

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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:
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  - 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.

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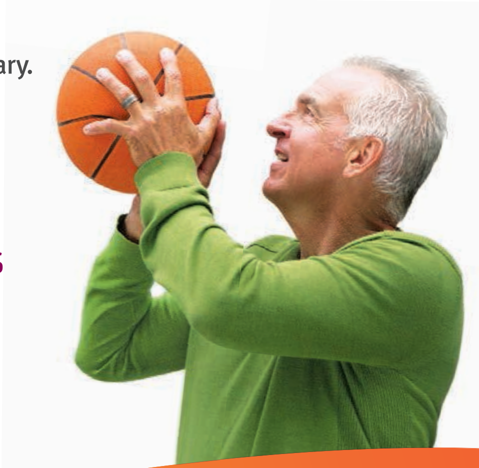

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IMPORTANT FACTS

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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).

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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.

Manufactured by:
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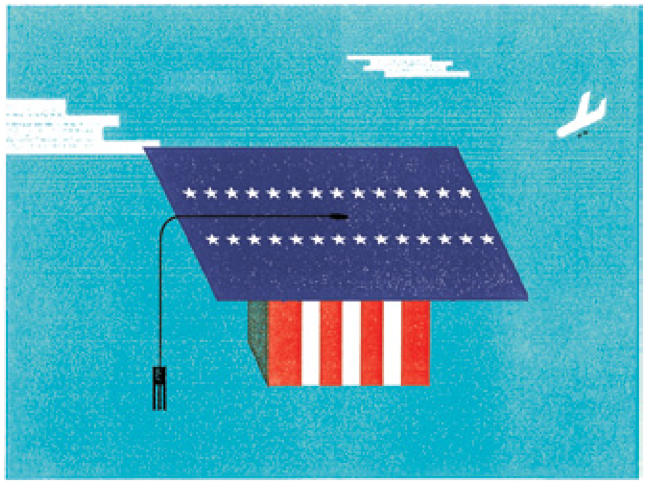
Princeton, New Jersey 08543 USA
Marketed by:
Bristol-Myers Squibb Company
Princeton, New Jersey 08543 USA
and
Pfizer Inc
New York, New York 10017 USA

Harold O. Levy was chancellor of New York City's public schools from 2000 to 2002. He is now managing director of Palm Ventures, a venture capital firm, where he leads the education practice.

Brain Exports

Why China, India and other nations love American universities



Can the U.S. stave off the erosion of its longtime preeminence in science and engineering? For decades the nation's stature in those disciplines has attracted many of the brightest and most talented students from around the world to America's advanced degree programs. Citizens of other countries now receive more than half the Ph.D.s awarded by U.S. universities in engineering, computer science and physics, on top of earning one third of all college degrees in science and engineering. In certain subfields, the disparity is much higher: in electrical engineering, for example, foreign students received 65 percent of all doctoral diplomas in 2001.

These figures should inspire alarm, not pride. The unpleasant truth is that the U.S. public education system simply does not produce enough high school graduates who are qualified for college work of any kind, let alone students with a vigorous appetite for math and the sciences. The full depth of America's educational failure is actually masked by the diversity of nationalities among grad students in those fields: Of the 1,777 physics doctorates awarded in 2011, for example, 743 went to temporary visa holders from many lands—and that figure excludes foreign nationals who had won permanent resident status. Only 15 of those 1,777 doctorates were earned by African-Americans.

The influx of students from abroad may now be reaching critical mass. Where economists used to bemoan the "brain drain" that afflicted much of the developing world, many foreign graduates are now taking their American diplomas and returning to their home countries in search of opportunities greater than those they see in the U.S. Stateside university master's programs are packed with foreign students who are scheduled to leave the country as soon as they graduate. In 2009, the most recent year for which such data exist, students on temporary visas earned 27 percent of all master's degrees in science and engineering, including 36 percent of those in physics and 46 percent in computer science. And a 2002 survey found that nearly 30 percent of those candidates had no firm commitment to lives in the U.S. after graduation. That study was conducted before the post-2007 decimation of the U.S. job market—and unless Congress can break its current stalemate, at press time, over immigration reform, the retention rate most likely will drop even further.

If and when those students depart from America, they will in effect constitute an unacknowledged version of foreign aid. The advanced education they receive in the U.S. is underwritten by American taxpayers in the form of sponsored research, financial aid (for foreign students as well as Americans), and a wide array of subsidies and grants. In addition, many state governments provide their local universities (including wholly private institutions) with land; buildings; subsidized construction loans; fire and police protection; massive real-estate and sales-tax exemptions; and, in a few states, annual budget allocations. Foreign nations—particularly China, India and South Korea—benefit hugely from U.S. investments in higher education.

Of course, just as with more conventional, overt foreign aid, America also stands to benefit from its own largesse. The presence of U.S.-educated people in other, developing countries makes it easier for America's style of commerce and manufacturing to be accepted there, and a shared understanding of professional norms, competencies and perspectives can only facilitate business relations with U.S. firms. But there are risks as well. If current trends continue, America's scientists and engineers—the basic drivers of innovation and prosperity—will ultimately be surpassed by U.S.-educated competitors in other countries that are more serious about teaching their youngsters.

To keep that from happening, America needs to strengthen math and science programs from kindergarten through grade 12. In April a consortium of 26 states took a major step in the right direction by issuing the Next Generation Science Standards, a set of curricular guidelines for elementary and secondary schools to get more students ready for college-level work. At least seven states have adopted the standards. The program, which is designed to emphasize hands-on investigative learning and to encourage critical examination of scientific evidence, has provoked resistance from some quarters where science itself is viewed with suspicion. Implementing the standards will cost money, too: America's stinginess in supporting K–12 science education is a persistent national problem. But we have little choice. The alternative is to keep on allowing the country's great universities to be used as a funnel for unintended foreign aid. SA

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Illustration by Oliver Munday

NEUROSCIENCE

Bionic Limbs, Rewired

The secret to building brain-controlled prostheses may be to ignore the brain entirely

In the past several years scientists have delivered a slew of advances in wiring prosthetic limbs directly to the brain. A number of studies have reported that severely disabled patients—or monkeys employed as research surrogates—have used bionic limbs controlled by thought to, say, pick up a cup or hold up a hand and give a high five.

Many of these devices have yet to become more than sophisticated laboratory showpieces that require constant fine-tuning to preserve a clear connection to the brain. Reliably reading the signals from electrodes implanted in the brain constitutes one of the grand challenges of neuroscience and biomedical engineering—and will occupy generations of researchers to come.

In the meantime, scientists and engineers have found a way to bridge the missing link. Instead of trying to decipher the cacophony of signals inside the brain, some researchers are configuring prostheses to take commands from the nerve endings left behind after an amputation.

Perhaps the best example to date is a robotic lower leg developed at the Rehabilitation Institute of Chicago. Scientists there fitted a cylindrical grid of 96 electrodes to the thigh of Zac Vawter, now 32 years old, after his lower leg had been amputated following a motorcycle accident in 2009. The electrodes in Vawter's thigh picked up signals from his brain at the peripheral nerve endings, instructing the artificial limb to walk or even climb steps, the doctors reported in September in the *New England Journal of Medicine.*

To overcome the engineering challenge of teasing out strong, clear signals from the nerves left in Vawter's leg, doctors attached the nerves that stimulate foot movements to residual muscles, which act as a natural signal booster. "Muscle will amplify the motor commands by about 1,000-fold," says Todd Kuiken, director of the institute's Center for Bionic Medicine.

Another new prosthesis used a similar peripheral link to relay signals the other way—from the limb to the brain—to convey a sense of touch. Researchers at Case Western Reserve University implanted tiny electrodes in the upper arm of an amputee and connected them to a robotic arm and hand. When sensors in the bionic hand detected pressure, the electrodes stimulated nerve endings to pass tactile information to the brain. The researchers tested the device by asking the patient to pull a grape off its stem while blindfolded. "He could hold it hard enough to pick up the grape but not so hard as to squish the fruit," says Dustin Tyler, an associate professor of biomedical engineering at Case Western.

Direct brain-to-prosthesis links will still be needed someday for patients whose damaged spinal cords impede nerve signals to the limbs. Until then, plugging into peripheral nerve outlets may help some of the one million leg amputees in the U.S. go for a smoother stroll. *—Gary Stix*

BRIAN KERSEY *AP Photo*

FURTHER READINGS AND CITATIONS ScientificAmerican.com/dec2013/advances

Q&A

Looking for a Flu Killer

The winner of the 2013 Google Science Fair on why more kids should e-mail scientists

What inspired your Google Science Fair project, in which you created six new potential flu drugs?
I live in San Diego, where some of the first cases of 2009 H1N1 swine flu took place in the U.S. It was then that I made the realization that flu can kill a lot of people. I thought, "Why can't we use the new computer power at our fingertips to speed up drug discovery and find new flu medicine?" I came across Dr. Rommie Amaro of the University of California, San Diego, and she was willing to let me work in her computational lab.

How did you find chemical compounds that would target and disarm a particular protein inside the flu virus?
I bounced between a computer lab and a biological wet lab. I first used computers to screen through a library of almost half a million compounds and reduce that to a top 237. Then I took those 237 and went to a biological wet lab and actually tested them for activity against the flu virus. I came out with those six top inhibitors.

One of the strategies you used is called molecular dynamic simulation. How does that work?
It uses supercomputer power to simulate every atom of a flu protein moving in solution. Previously, scientists had worked with static snapshots of this same protein.

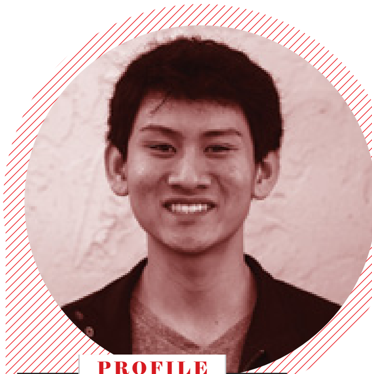
With molecular dynamic simulation, you can see all the possible pockets within a protein that you could build your inhibitor into and what fraction of the time these pockets appear.

What's next?
These are still pretty early in the drug-discovery pipeline. I haven't done any animal studies. What I'm now working on is giving these inhibitors good druglike traits. They have to be very potent, first of all, but they also can't be toxic.

You also do a lot of science outreach to younger kids. Why is that important to you?
Ever since I was 15, I was very, very driven to do research, and because of that I ran right through obstacles, such as e-mailing professors I didn't know. But a lot of these younger students, they're afraid to try.

I'm really trying to dig in the idea that when you do scientific research, you're doing stuff that nobody has done before. If I can give other students a taste of that discovery feeling, they may be more willing to face future obstacles.

—Anna Kuchment



PROFILE

NAME
Eric Chen

AGE
17

TITLE
Senior, Canyon Crest Academy

LOCATION
San Diego, Calif.

BY THE NUMBERS

1.5

Minimum temperature increase, in degrees Celsius, that the world is likely to experience by 2100 relative to 1850–1900 levels unless carbon emissions are rapidly reduced.

ANDREW FEDERMAN (*top*); SOURCE: "CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS." WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (*bottom*)

COMMENT AT ScientificAmerican.com/dec2013

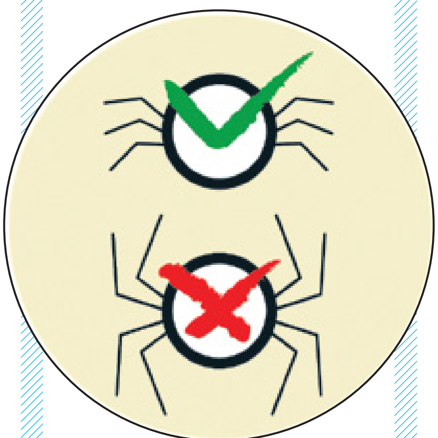
PSYCHOLOGY

Bugs, Yes. Spiders, No

Even entomologists can't stomach some creepy-crawlies

Retired entomologist Rick Vetter understands that not everyone shares his passion for spiders. But he was surprised to learn that even some of his colleagues, who willingly study six-legged insects, abhor eight-legged arachnids.

Vetter first noticed the spider antipathy during his career at the University of California, Riverside, where his colleagues sometimes recoiled in horror at his brown recluses and black widows.



Intrigued, Vetter arranged a survey of 41 spider-fearing entomologists. Most of their aversions qualified as a mild dislike, but some ranked as full-blown, debilitating arachnophobia, Vetter reported in *American Entomologist*. As is common with phobias, many of the scientists traced their fears to a traumatic childhood experience.

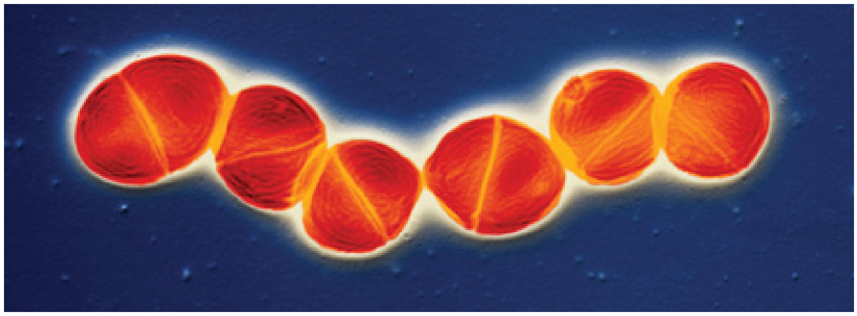
Asked to score 30 animals on likability, the respondents ranked spiders 29th. (Only ticks drew more scorn.) Among the reasons given for detesting arachnids: the spiders' many legs and the "unsettling" ways they move. "Even filling out the survey creeped me out," one researcher wrote. —*Rachel Nuwer*

Illustrations by Thomas Fuchs

BIOLOGY

Breaking Bad, Bacteria-Style

What makes a normally harmless microbe turn deadly?



SCIENCE SOURCE

Bacteria are all around—and inside—us. Some are harmless, some are beneficial and some, of course, cause disease. Others, such as the common bacterium *Streptococcus pneumoniae,* defy categorization. They are turncoats, with the ability to suddenly switch from good to bad.

Usually the microbe dwells harmlessly in people's nasal passages. Every so often, however, when *S. pneumoniae* senses danger, it disperses to other areas of the body in a bid to save itself, making us sick. The bacteria cause serious disease, such as pneumonia, which is the leading cause of childhood death worldwide, "but they are accidental pathogens," says Anders Hakansson of the University at Buffalo.

Evidence has shown a strong correlation between illness from influenza and subsequent infection by *S. pneumoniae,* but just how the bacterium turns virulent has remained murky. So Hakansson and his colleagues set out to investigate.

They found that the change seems to be triggered by the human immune response to the flu. When the body responds to a flu virus by raising the temperature and releasing stress hormones such as norepinephrine, the bacteria react in turn to those changes in their environment. They disperse from their colonies and begin expressing different genes that make them more deadly to respiratory cells, the team reported in *mBio.*

The ability of *S. pneumoniae* to intercept hormones and other distress calls from human cells exemplifies a phenomenon called interkingdom signaling—in this case, a bacterium tuning in to signals from the animal kingdom—which is gaining recognition as a key biological mechanism. Hakansson notes that because *S. pneumoniae* is native to humans, it makes sense that the microbe would have evolved ways to read changes in the landscape. Says Hakansson: "We are the bacteria's ecological niche." *—Robyn Braun*

COMMENT AT ScientificAmerican.com/dec2013

TECHNOLOGY

FIFA Physics

How a soccer video game finally got air resistance right

When the soccer video game FIFA 14 went on sale this past fall, it boasted a ball that, at long last, could sail smartly through the air. In earlier versions of the popular game, the ball sometimes became a bit "floaty," soaring along an unrealistically linear path.

Last year a team of engineers and animators vowed to get to the bottom of the problem. After an intense audit of all the projectile physics code in the game, they found the problem: their drag coefficient was wrong.

Engineers use the drag coefficient to model air resistance, which affects the speed and trajectory of an object in flight. "The ball moves at its fastest velocity when it comes right off the foot, and air resistance immediately slows it down until it reaches its maximum height," says John Eric Goff, a physicist at Lynchburg College and author of *Gold Medal Physics: The Science of Sports.* "The ball should then pick up speed on its way down."

In previous FIFA versions the ball violated the laws of physics, accelerating and decelerating at a set rate unaffected by its initial velocity. "So if the ball was moving at 30 or 50 miles per hour, it was going to slow at the same rate as if it were moving at five miles per hour," says Aaron McHardy, a senior gameplay producer at EA Sports, the company that produces the FIFA franchise.

The drag glitch also made for unrealistic spin. As a spinning ball whips air off to one side, the so-called Magnus effect pushes the ball in the opposite direction. A miscalculated Magnus effect meant the ball was not curving with much variability. "Once fixed, the ball would spin appropriately, and we got so much more variety in the curve," McHardy says. "The ball now finally dips and swerves and does all these things that we see in the real world." *—Julianne Chiaet*

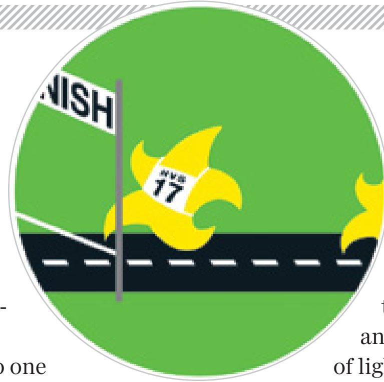
ASTROPHYSICS

Escape from the Milky Way

Stars racing out of the galaxy could offer clues about dark matter

All stars are in motion, but some have a little more oomph than others. In recent years astronomers have identified a handful of stars that are moving so fast that they will someday flee the galaxy altogether.

On their way out, these escapees may tell us a thing or two about the nature of dark matter, the mysterious stuff that makes up nearly 85 percent of all matter in the universe. "No one knows what dark matter is," says astrophysicist Warren Brown of the Smithsonian Astrophysical Observatory. Yet astronomers know it exerts a gravitational pull, which bends the paths of objects traversing the galaxy. Outbound stars thus act as tracers to reveal where dark matter is concentrated, and physicists can use that information to test competing theories of how it behaves.



The catch is that no one is quite sure what paths these stars are on. To use them as dark matter probes, astronomers need to know the stars' full trajectories, starting from the spot where they shot outward with such force. One possibility: the stellar speedsters were ejected by supernova explosions in the galaxy. Or perhaps they drew too close to the supermassive black hole at the Milky Way's center, which flung them out like stones in a slingshot. If that were the case, each star would trace back to a known point. "If they really come from the galactic center, then that's very valuable," says University of Maryland astrophysicist Michael Boylan-Kolchin.

But how to tell where a star came from? Brown and his colleagues say that it boils down to a star's age, speed and position. Through a careful analysis of the spectrum of light from the newfound star HVS17 (short for hypervelocity star 17), the team determined it was 153 million years old and traveling about one million miles an hour through the outer Milky Way. A supernova-launched star would be much younger, having been ejected from its stellar cohort soon after forming by the detonation of a short-lived neighbor. The star's advanced age, then, argues for an origin near the galactic center, according to a recent study the researchers published in the *Astrophysical Journal*. New data from the European Gaia satellite should conclusively settle the star's origin and cast a sliver of light on dark matter. —*Nathan Collins*

COMMENT AT ScientificAmerican.com/dec2013

MANOJ SHAH *Getty Images*

BEHAVIOR

Play Nice

Chimps need parental guidance to safely horse around

In central Zambia, at the Chimfunshi Wildlife Orphanage, dozens of parentless chimpanzees are raised among their peers, without adults. The arrangement is a lucky one for the chimps: in the wild, orphanhood can mean death.

Yet the parentless life—even at a refuge—has its drawbacks. Across a wide range of social species, research has demonstrated how normal social development depends on the presence of mature individuals, which leaves orphans at a disadvantage.

To find out how maternal rearing shapes chimp interactions, researchers watched two populations of Chimfunshi juveniles at play: one group of orphans and one of chimps that were raised by their mothers. Surprisingly, the orphans initiated play more often than the mother-reared group. "I was relieved to find that the orphans were very motivated to try and engage in playful interactions because these are commonly seen as a sign of psychological health," says graduate student Edwin van Leeuwen, who led the research at the Max Planck Institute for Psycholinguistics in Nijmegen, the Netherlands.

Although the orphaned chimps liked to play, they were not always good at it. Most of their bouts lasted less than 60 seconds, whereas the mother-reared chimpanzees were more likely to play for a few minutes at a time. Furthermore, the orphans' behavior was more than five times as likely to escalate into aggression, according to the study, published in *Animal Cognition*.

What keeps the mother-reared chimps' play from turning ugly? It could be that they have learned to use subtle signals that maintain a relaxed atmosphere. Many play behaviors, such as gnawing and hitting, are easily mistaken for aggression, and growing up around adults may allow youngsters to learn the rules of friendly engagement.

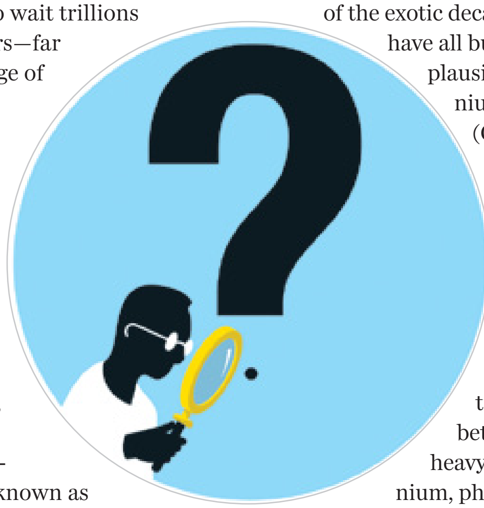
Or perhaps a mother's strict oversight from early on sets lasting boundaries. If mothers consistently step in when play gets out of hand, "then over time, the mother-reared ones will have learned not to escalate," says Claudio Tennie, an ape researcher at the University of Birmingham in England.

The good news for orphaned juveniles is that they still have time to learn social norms. "Orphans can grow up to become relatively socially competent," van Leeuwen says, "as long as they have a chance to live their lives freely in a large and appropriate environment with many others." He adds that Chimfunshi has four such groups with grown-up orphans and that overall "they seem to be healthy and stable and exhibit typical chimpanzee behavior." —*Jason G. Goldman*

PHYSICS

Waiting for a Neutrino No-Show

Physicists line up to crack a long-standing particle puzzle



"Rare" may be too generous a term for the phenomenon called neutrinoless double beta decay, a burst of radioactive emission in which two neutrinos cancel each other out and vanish. To observe the nuclear process in a single atom, you might have to wait trillions of trillions of years—far longer than the age of the universe.

Then again, neutrinoless double beta decay may not happen at all. No one has ever seen it, but physicists are keen to observe the phenomenon, which would indicate that the beguiling particles known as neutrinos have many new secrets to reveal.

Whereas most hunts in particle physics try to net specific particles in a detector, neutrinoless double beta decay experiments look for a telltale absence of particles. The decay is a variant of double beta decay, a better-understood nuclear process in which radioactive atoms transmute from one element to another (changing, say, from xenon to barium), releasing a pair of electrons and a pair of neutrinos as by-products. But if neutrinos are their own antimatter counterparts, as many physicists suspect, the two neutrinos can cancel out. Experimenters thus look for all the characteristics of double beta decay, minus the neutrinos.

If it exists in nature, the neutrino disappearing act would open up several new realms for investigation. "Neutrinoless double beta decay is the smoking gun for new physics," says Carter Hall, a physicist at the University of Maryland. Most tantalizing, perhaps, neutrinos and antineutrinos being one and the same would imply that the neutrino does not get its mass from the Higgs boson, as do most of the other elementary particles, but from some other, unresolved mechanism. The dual nature of neutrinos might also help explain why antimatter is so scarce in our universe.

A glimmer of hope appeared in 2001, when a cadre of physicists working on the Heidelberg-Moscow Double Beta Decay Experiment claimed to have caught sight of the exotic decay. But new data have all but extinguished its plausibility. The Germanium Detector Array (GERDA) in Italy, which should by now have been able to corroborate the Heidelberg-Moscow claim, has so far come up empty in its search for neutrinoless double beta decay from a heavy isotope of germanium, physicists reported in September in *Physical Review Letters*. Next year upgrades to the experiment will increase GERDA's sensitivity, pushing into the range where many neutrino researchers predict the phenomenon will be detectable.

Physicists are also sifting through the particles given off by other radioactive atoms for which neutrinoless double beta decay is hypothetically possible. Last year researchers presented early data from new experiments called KamLAND-Zen in Japan and EXO-200 in New Mexico, both of which look for decays from an isotope of xenon. Neither has yet found any evidence for neutrinoless decay, but for the first time in the decades-long pursuit of the elusive phenomenon, physicists have experiments that can get them there. —*Calla Cofield*

COMMENT AT ScientificAmerican.com/dec2013

EXTINCTION COUNTDOWN: SANTA CRUZ CYPRESS

Rare California Cypress Is Recovering under Federal Protection

Forty years ago this month then president Richard M. Nixon signed the Endangered Species Act, a vital piece of legislation that has been called one of the world's most effective environmental laws.

One recent beneficiary of the legislation is the Santa Cruz cypress. The California evergreen thrives after natural forest fires, which serve to open its cones and release its seeds. As humans have settled in the surrounding Santa Cruz Mountains and learned to bring fires under control, the tree has suffered. When the U.S. Fish and Wildlife Service added the cypress to the endangered list in 1987, its few remaining groves were imperiled by development.

Today those threats have mostly abated. Four of the five remaining Santa Cruz cypress habitats are now parklands or ecological reserves. The population comprises a healthy 33,000 trees or more, so the FWS has proposed reclassifying the species as merely "threatened."

Only a handful of protected species have ever rebounded enough to be delisted entirely, but like the cypress, most have stabilized and survived. "We view success as preventing a species from going extinct—to keep it from sliding further," says Gary Frazer, assistant director for endangered species at the FWS. "We've been very successful at that." *—John R. Platt*

COURTESY OF JOEY MALONE

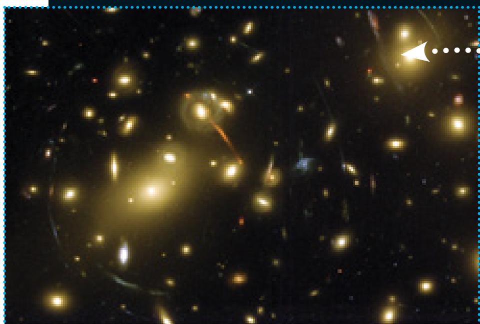
Read twice-weekly updates at blogs.ScientificAmerican.com/extinction-countdown

ASTRONOMY

Kepler's Second Life

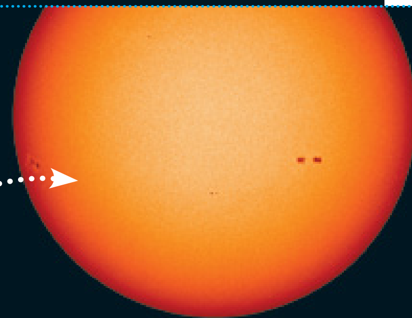
NASA is investigating new roles for the former planet-hunting observatory

The Kepler telescope is down but not out. The observatory was NASA's preeminent planet-hunting machine until May, when a mechanical failure on the spacecraft cost Kepler its precise pointing ability and, with it, the power to discover small exoplanets that could be similar to Earth. But space telescopes—even banged-up ones—are hard to come by, so NASA put out a call for ideas on how to repurpose Kepler. In response, scientists suggested more than 40 new missions for the spacecraft. Some are modified ways to carry on the search for planets, whereas others represent new directions altogether. Here are four intriguing blueprints for Kepler's second life. *—Clara Moskowitz*



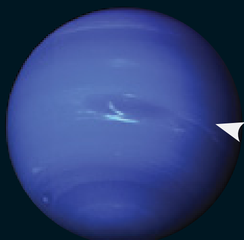
BEYOND THE MILKY WAY

If Kepler turned toward regions packed with bright galaxies, it could hunt for gorging black holes and identify stars likely to go supernova. It might even get an unprecedented view as the explosions unfolded. Even in its hobbled state, "there are no existing or planned facilities that could observe supernova explosions as well as Kepler," researchers wrote in a proposal.



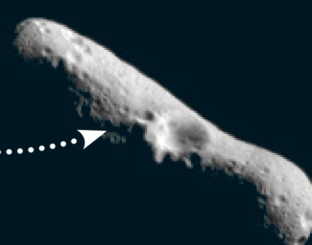
QUAKING STARS

Just as earthquakes shake our planet, "starquakes" rattle stars, causing brightness variations that reveal the stars' inner dynamics. Kepler could be used for asteroseismology—tracking starquakes—in a cluster of Milky Way stars called NGC 2244. The cluster is filled with a poorly understood variety of hot, massive stars.



WAVES OF BLUE

Observing how Neptune oscillates—brightening and dimming as heat cycles through its interior—would probe the planet's structure. "We don't know all that well what the interiors of the giant planets look like," says Mark Marley of the NASA Ames Research Center.



WATCH FOR FALLING ROCKS

Kepler could speed the discovery of nearby asteroids, many of which are large enough to do serious damage to Earth (although few are as big as Eros, *above*). "Kepler can look inside Earth's orbit—that's a region where we have very little info about near-Earth objects," says Kevin Stevenson of the University of Central Florida.

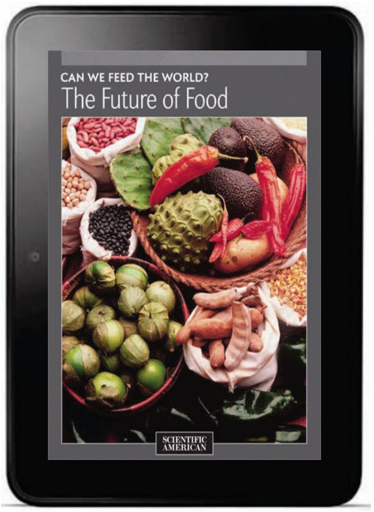
COURTESY OF NASA (*Kepler*); SCIENCE SOURCE (*galaxies*); COURTESY OF NASA/JPL (*Neptune*); AP PHOTO (*sun and asteroid*)

COMMENT AT ScientificAmerican.com/dec2013

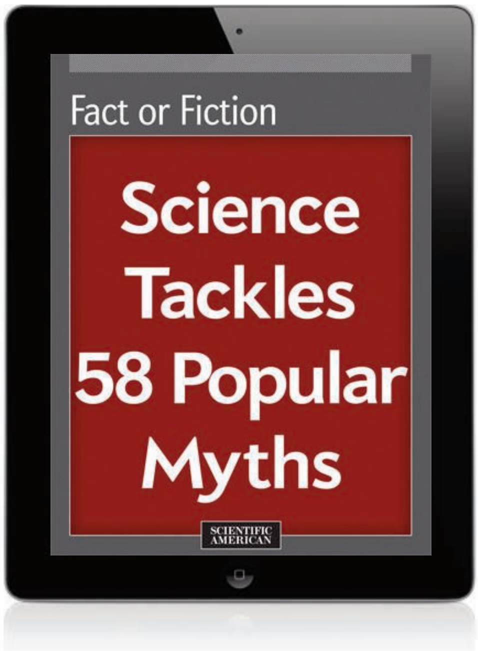
EBooks that raise your tablet IQ

Science to enrich your life in a format to fit your lifestyle

From the Editors of Scientific American



A companion to *Scientific American's* special September 2013 issue, this eBook looks at some of the complex factors involved in the coming "food crisis." With the global population projected to reach 9 billion by 2050, is it possible to increase food production and distribution both sustainably and safely?



Did NASA really spend millions creating a pen that would write in space? Is chocolate poisonous to dogs? Does stress cause gray hair? These questions are just a sample of the urban lore investigated in this eBook. We've selected 58 of the most surprising, fascinating, useful and just plain wacky topics our writers have confronted over the years.

Addiction is costly on many levels to the individuals affected, their families and society as a whole, but science may soon be able to offer treatment options to make the road to recovery a little smoother. In this eBook, we tackle the many facets of this complex issue.

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ZOOLOGY

Follow the Leader

Researchers are unlocking the secrets of how fish swim in coordinated schools

School of barracuda

The minnows known as golden shiners put on displays of synchronized swimming that could impress even the toughest Olympic judge. The ability of shiners and other fishes to change direction in harmony has long intrigued scientists, who have developed several ways of describing in mathematical terms how schooling works. But those approaches tend to be simplifications that do not take into account all the real-time sensory information available to the fish.

To get a better idea of what the fish were actually doing, Princeton University biologist Iain Couzin and his colleagues devised a way to make golden shiners move en masse and on cue. The researchers taught a few fish to swim toward a green light to find food and then placed those fish in a larger school. When the light went on, the trained fish broke toward it, triggering a cascade of responses as the rest of the school fell in behind the leaders.

Couzin and his colleagues filmed the action with high-speed video that allowed the researchers to map each fish's visual field using the location and position of its head. The researchers reported in *Current Biology* that each fish based its decisions on where to go not on the behavior of its nearest neighbors, as is often assumed, but on a synthesis of where all the fish in its field of view were headed.

"We could pinpoint the exact moment that a fish started moving toward the light, and we found the fish were responding to the fraction of individuals they could see that had also started moving," Couzin says.

Meanwhile other researchers are working to uncover what makes some fish school in the first place. Katie Peichel, a biologist at the Fred Hutchinson Cancer Center in Seattle, and her colleagues have found that schooling in three-spined sticklebacks depends on behaviors linked to at least two distinct groups of genes. Her group reported in *Current Biology* that one cluster of genes controls a fish's propensity to join others in a large group; another set of genes influences how well a fish swims in formation, parallel to its neighbors.

Together the behavioral traits and sensory abilities of schooling fish produce dazzling maneuvers that help fish avoid or defend against predators. "By grouping together, they're sensing the world in a different way," Couzin says. —*Carrie Arnold*

BY THE NUMBERS

95%

Minimum likelihood of humans being "the dominant cause of the observed [global] warming since the mid-20th century," according to the recent Intergovernmental Panel on Climate Change report.

99%

Minimum likelihood "that there will be more frequent hot and fewer cold temperature extremes" as the planet warms. Heat waves will "very likely" occur more often and last longer.

DOUG PERRINE *Getty Images* (*top*); SOURCE: "CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS," WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (*bottom*)

COMMENT AT ScientificAmerican.com/dec2013

BASIC RESEARCH

Ugly Science Pays Off

Why it's worth spending $250,000 to research worm sex

Sometimes the greatest scientific discoveries come from research that seems simplistic, esoteric or flat-out bizarre. The weirder the better for the organizers of the Golden Goose Awards. Sponsored by a number of leading scientific societies, the awards were launched last year to celebrate the importance of federally funded basic research projects that may sound quirky but sometimes deliver tremendous payoffs.

"When you call somebody and tell them you'd like to present them with a Golden Goose Award, their first question is often, Is this a joke? Who is this, really?" says Barry Toiv, one of the organizers and vice president of public affairs for the Association of American Universities. "Once you explain it, they get it, and our recipients have all seemed to deeply appreciate the recognition."

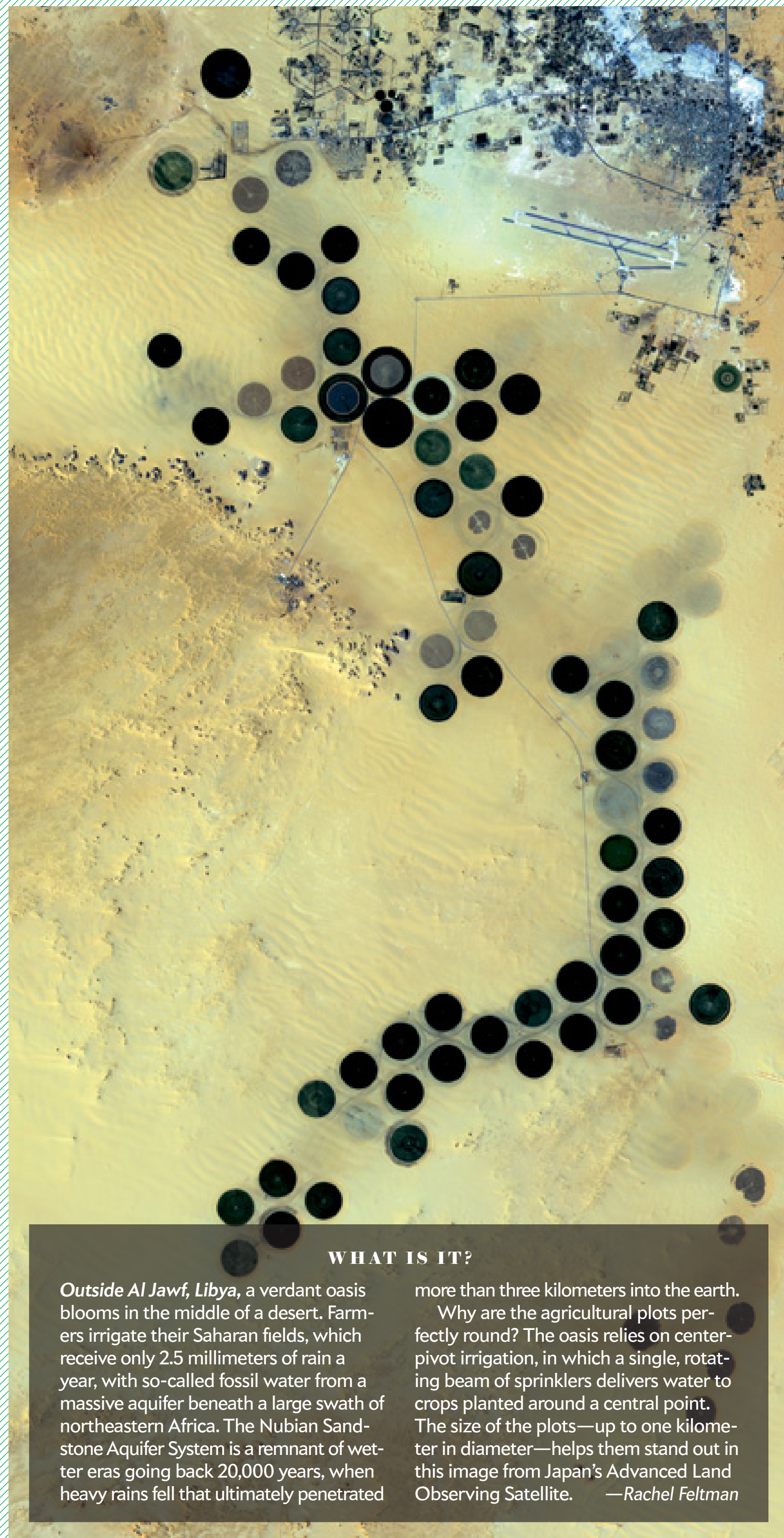
This year's awardees included Thomas Brock, who in the 1960s used a National Science Foundation grant to discover a heat-loving bacterium called *Thermus aquaticus* in a hydrothermal pool at Yellowstone National Park. An enzyme extracted from that microbe is now a key part of the polymerase chain reaction, which amplifies small samples of DNA for study—and which powers a multibillion-dollar industry of genetic analysis. "I was doing basic research on organisms at high temperatures and focusing on evolution and ecology," Brock says. "I wasn't even thinking about industrial uses."

Another honoree, John Eng, found in 1992 that the poisonous saliva of the Gila monster lizard could stimulate insulin production, which led to the development of the diabetes drug exenatide. "A lot of research doesn't end in major discoveries," says Eng, who worked for the Department of Veterans Affairs at the time. "But it might, and I don't think anyone can predict which will."

The Golden Goose Awards were inspired by the Golden Fleece award, which the late Wisconsin senator William Proxmire dished out in the 1970s and 1980s to bring attention to what he viewed as wasteful government spending. Instead Proxmire often targeted valuable research.

Proxmire once mocked the U.S. Department of Agriculture for investing $250,000 to explore the sex life of the screwworm. But the federal investment paid off handsomely. The study of the livestock parasite showed that female screwworms mate only once, whereas males mate many times. By creating a host of sterile male worms and releasing them in the wild, USDA scientists eradicated the pest, saving the livestock industry billions of dollars. Ultimately even Proxmire came around to acknowledging the importance of the research.

Nowadays, as federal budgets constrict, funding for basic research is in the crosshairs once again. With the Golden Goose Awards, Toiv and his colleagues aim to remind policy makers that even worm voyeurism can yield innovations that the country needs. —*Rachel Feltman*



WHAT IS IT?

Outside Al Jawf, Libya, a verdant oasis blooms in the middle of a desert. Farmers irrigate their Saharan fields, which receive only 2.5 millimeters of rain a year, with so-called fossil water from a massive aquifer beneath a large swath of northeastern Africa. The Nubian Sandstone Aquifer System is a remnant of wetter eras going back 20,000 years, when heavy rains fell that ultimately penetrated more than three kilometers into the earth.

Why are the agricultural plots perfectly round? The oasis relies on center-pivot irrigation, in which a single, rotating beam of sprinklers delivers water to crops planted around a central point. The size of the plots—up to one kilometer in diameter—helps them stand out in this image from Japan's Advanced Land Observing Satellite. *—Rachel Feltman*

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COMMENT AT ScientificAmerican.com/dec2013

Ingfei Chen is a freelance writer based in Santa Cruz, Calif. Her articles have appeared in the *New York Times*, *Science* and *Smithsonian*, among other publications.

Scanning for Alzheimer's

A new test can identify the disorder's early stages. How will it help patients?

The way doctors diagnose Alzheimer's disease may be starting to change. Traditionally clinicians have relied on tests of memory and reasoning skills and reports of social withdrawal to identify patients with Alzheimer's. Such assessments can, in expert hands, be fairly conclusive—but they are not infallible. Around one in five people who are told they have the neurodegenerative disorder actually have other forms of dementia or, sometimes, another problem altogether, such as depression. To know for certain that someone has Alzheimer's, doctors must remove small pieces of the brain, examine the cells under a microscope and count the number of protein clumps called amyloid plaques. An unusually high number of plaques is a key indicator of Alzheimer's. Because such a procedure risks further impairing a patient's mental abilities, it is almost always performed posthumously.

In the past 10 years, however, scientists have developed sophisticated brain scans that can estimate the amount of plaque in the brain while people are still alive. In the laboratory, these scans have been very useful in studying the earliest stages of Alzheimer's, before overt symptoms appear. The results are reliable enough that last year the Food and Drug Administration approved one such test called Amyvid to help evaluate patients with memory deficits or other cognitive difficulties.

Despite the FDA's approval, lingering doubts about the exact role of amyloid in Alzheimer's and ambivalence about the practical value of information provided by the scan have fueled debate about when to order an Amyvid test. Not everyone who has an excessive amount of amyloid plaque develops Alzheimer's, and at the moment, there is generally no way to predict whom the unlucky ones will be. Recent studies have shown that roughly one third of older citizens in good mental health have moderate to high levels of plaque, with no noticeable ill effects. And raising the specter of the disorder in the absence of symptoms may upset more people than it helps because no effective treatments exist—at least not yet.

A new clinical trial will investigate whether giving an experimental drug as soon as the scans detect the formation of plaques can slow or halt the development of Alzheimer's. Even if the results are encouraging, a new drug will take many years to reach the market, and doctors must still determine how to use the scan responsibly in the meantime. "The whole field is grappling with

Illustration by Davide Bonazzi

this," says neurologist Reisa Sperling of Brigham and Women's Hospital. She thinks the scan could bring clarity to challenging diagnoses, but "as a predictive test, it's not ready."

TELLTALE TROUBLE

SCIENTISTS FIRST LINKED amyloid plaques to what is now called Alzheimer's disease more than 100 years ago. In 1906 German psychiatrist Alois Alzheimer documented unusual protein knots in the brain of a deceased dementia patient. By the mid-1980s scientists determined that such plaques are made up of a protein they named beta-amyloid.

Healthy neurons produce plenty of beta-amyloid, but its precise purpose remains a mystery. In the initial stages of Alzheimer's and other neurodegenerative disorders, the proteins begin to behave strangely, sticking together to form larger and larger clumps. Scientists are still unsure whether the resulting plaques are primarily responsible for the devastating loss of millions of neurons that characterizes Alzheimer's or whether they are, instead, a by-product of some other, as yet undetermined, cause.

Nevertheless, the clumps form long before any explicit signs of dementia, and numerous plaques remain one of the best indicators of the disorder. Neurologists John C. Morris, Randall Bateman and their colleagues at Washington University in St. Louis have been tracking the health of people with a rare genetic mutation that guarantees Alzheimer's will strike them at a young age. They have detected amyloid plaques in the brain 15 years before cognitive problems typically appear in such individuals.

Attempts to design a scan that could spot amyloid first began about a dozen years ago at the University of Pittsburgh. Researchers injected patients with a small, benign amount of a radioactive dye they named Pittsburgh compound B, or PIB. The dye traveled through the blood to the brain and clung exclusively to clusters of amyloid protein. Scanning the brain with a positron-emission tomography (PET) machine then produced images that highlighted any plaques by detecting radiation in the form of gamma rays emanating from the dye.

Scientists at Philadelphia-based Avid Radiopharmaceuticals built on the Pittsburgh approach by developing Amyvid, a longer-lasting dye that gave clinicians more time to scan their patients. Early results were so promising that Eli Lilly bought the company in 2010 for $300 million. Two years later the FDA approved the Amyvid test, which more than 450 imaging centers in the U.S. now offer, usually for $3,000 or more.

TO SCAN OR NOT TO SCAN

TOGETHER THE FDA and the neurological community have approached Amyvid with a mix of enthusiasm and trepidation. Officially the test has been approved primarily to exclude Alzheimer's as a diagnosis for someone who already has cognitive impairment, which is particularly helpful when the causes are unclear. This past January an expert task force convened by the Alzheimer's Association and the Society of Nuclear Medicine and Molecular Imaging published guidelines that advised limiting the test's use to patients with unexplained, persisting mild cognitive impairment (MCI) and to those who either have developed dementia unusually early or have dementia with atypical symptoms, such as hallucinations or delirium. Determining whether Alzheimer's is the culprit in such cases has always been difficult, and Amyvid is exactly the kind of tool that can provide some assistance. If a scan finds few plaques, physicians can more confidently rule out Alzheimer's and explore other explanations, such as a rare and rapid degeneration of the brain's frontal lobes.

The task force also advised against amyloid scans for people with no cognitive impairment. Panelists worried not only that amyloid-positive results might send some vulnerable individuals spiraling into depression or perhaps even suicide but also that the information may make it harder for them to get long-term care insurance or renew a driver's license, says task force member Jason Karlawish, a professor of medicine and medical ethics at the University of Pennsylvania.

Despite these cautious guidelines, which Eli Lilly supports, many people in the medical community have reservations. Task force member and neurologist Norman Foster of the University of Utah worries that some doctors and patients will rely on amyloid scans as a diagnostic shortcut in lieu of a more thorough evaluation that includes a battery of memory and reasoning tests. And given the lack of effective treatment, a scan suggesting that someone with mild cognitive impairment has early Alzheimer's may yield more anxiety than practical guidance. "What do you do with that information?" asks neuroscientist William Jagust of the University of California, Berkeley.

Some experts think that if scans help patients and their families prepare for the changes in health and lifestyle that come with Alzheimer's, then they are beneficial. Others argue that the test is not meaningful if it does not alter how a patient is treated. The federal agency that oversees Medicare insurance essentially took the latter view in September, when, because of insufficient evidence that the scan improves patient health, it declined to cover Amyvid for now except in certain clinical trials. Though disappointed, Avid's CEO Daniel Skovronsky acknowledges that figuring out how best to use the scan will take considerable time and debate because it is such a new tool. "I think the discussion is actually a good thing," he says.

The clinical trial slated to begin this month could help quell the controversy if its results are auspicious. In that study, Sperling, Karlawish and investigators at 60 U.S. medical centers aim to screen 3,000 healthy senior citizens to identify 1,000 amyloid-positive individuals who will receive either a drug therapy for Alzheimer's called solanezumab or a placebo for three years.

Before anybody slides into a PET scanner, however, participants will be prescreened for mood, depression and anxiety to ensure they are capable of "handling uncertainty and, potentially, what could be construed as bad news if they learn that they are amyloid-positive on imaging," Karlawish says. "There will be some people who are not, frankly, allowed to go forward."

With any luck, the trial's results, which are not expected until 2018, will confirm that solanezumab could become a viable treatment in the future, as well as help doctors decide whether it makes sense to get an early look at Alzheimer's today. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/dec2013

David Pogue is the personal-technology columnist for the *New York Times* and an Emmy Award–winning correspondent for *CBS News.*

The Problem with Lego Phones

Could snap-together cell phones surmount the obsolescence problem?

We all know that the cycle of electronics consumerism is broken. Because it's an endless money drain for consumers to keep their gadgets current. Because the never ending desire to show off new features leads to bloat and complexity of design. And because all our outdated, abandoned gadgets have to *go* somewhere. According to the U.S. Environmental Protection Agency, we Americans threw away 310 million electronic gadgets in 2010 alone. That's about 1.8 million tons of toxic, nonbiodegradable waste in our landfills.

At least somebody's expressing concern about this problem—nearly 15 million somebodies, actually. That's how many people have watched a viral YouTube video called *Phonebloks,* which touts a new phone concept by Dutch designer Dave Hakkens.

Hakkens wants the people of Earth to rise up and demand a new kind of cell phone, in which the various components—camera, processor, GPS, screen—snap together like Legos.

This system, he says, would let you build exactly the phone you want. If you keep your files online, you could remove the storage module and replace it with a bigger battery. If you are older, you could unplug the camera and replace it with a bigger speaker.

Above all, though, he suggests that the Phonebloks concept would dramatically cut down on e-waste. You wouldn't throw away a phone every other year; instead you'd own just one phone that's built—and rebuilt—to last. If one component broke or became obsolete, you'd just unplug it and replace it with a new one.

Clearly, this concept is consumer catnip. It offers the promise of staying current—without the guilt. And of saving us money *and* of making it easy for anyone to build a customized phone.

There's only one hitch: Phonebloks will never happen.

The first problem: physics. Today's smartphone is a miracle of miniaturization. To keep the size small, the speed up and the battery life long, the components are packed in as closely as possible. In Apple's iPhone, for example, the memory, the processor and the graphics circuitry are all built into a single chip. A Phonebloks phone would introduce relatively gigantic distances between these elements, which would kill the battery life, speed and size.

Which brings us to the second problem: bulk. Steve Jobs refused to put a removable battery on the iPhone for this reason. A removable battery has to be enclosed in rigid walls so that you, the human, can handle it safely. If *every* component of your phone were a self-contained, sealed box like that battery, you'd have one very boxy, very bulky, very heavy phone.

The third problem: given the limited real estate, today's smartphone engineers sweat over component placement. Where should the antennas go for the best reception? Where does the speaker go for best audio? With free placement of any block on a Phonebloks phone, you would lose enormous advantages of quality, convenience and speed.

The fourth problem: economics. The Verizons and AT&Ts of the world *love* that we throw away our phones every other year; indeed, locking us into new two-year contracts is their business model. Why would they support any movement that would disrupt their herd of cash cows?

And finally: aesthetics. Who would buy the big, boxy, gray, sharp-cornered prototype illustrated in the video?

You want to love the Phonebloks concept. You'd love to have more control, greater savings and less guilt. Unfortunately, you'd pay quite a penalty: your phone would be big, heavy, slow, hot, fragile and ugly. Some analysts have even asserted that we would wind up with *more* electronic waste, a result of consumers discarding more modules more frequently.

There is some good news on the discarded-phone front: from all indications, the smartphone is maturing. The improvements in each year's new models are getting less dramatic. These days it's primarily the software that distinguishes your iPhone from your Samsung—and software leaves nothing in landfills.

Even so, e-waste and obsolescence remain distressing problems. No, Phonebloks is not the solution. But at least it has drawn attention to our current system—and just how broken it is. SA

SCIENTIFIC AMERICAN ONLINE
Four more seemingly brilliant tech flops: ScientificAmerican.com/dec2013/pogue

Illustration by Hank Osuna

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Kentucky: RACING AHEAD IN INNOVATION

When the Rev. Thomas Robert Malthus penned "An Essay on the Principle of Population" in 1798, the reverberations from his message were felt throughout the intellectual world. A skeptical treatise on the world's growing population, the work suggested that future man was doomed to poverty both by decreasing wages and limited natural resources.

While Malthus' Iron Law of Population precipitated a national census in England, many non-intellectuals in the New World came to view the work as pure bunk, their arguments bolstered by ever-increasing crop yields – the product of new, effective agricultural methods.

None of this stopped the world's population from growing.

Today, the world stands at the same precipice it did in 1798. But the numbers are much more dizzying. Yet once again, an important technological revolution is taking place, including some state-of-the-art technological developments in the Commonwealth of Kentucky.

The state, known for its thoroughbred horse racing and its excellent bourbon, is racing ahead in innovation. And its efforts are attracting new companies and entrepreneurs, with new innovations that may provide the world with inexpensive fuels, food resources and medical miracles for decades to come.

SPARKING AUTOMOTIVE INTEREST

Kentucky already is home to a burgeoning automotive industry. Attracted by the state's quality workforce, low utility costs and a business-friendly climate, General Motors, Toyota and Ford all have major assembly and manufacturing operations in the state.

The average cost of power in the Commonwealth in July 2013 was 5.97 cents per kilowatt-hour compared to 7.32 cents per kilowatt-hour for the national average, according to statistics from the U.S. Energy Information Administration. Citing utility costs as among the most significant factors on a business's bottom line, site selectors responding to a 2011 *Area Development* magazine survey gave the Commonwealth the top position in the provision of low-cost electric power among all states in the union. A recent report by CNBC also stated that Kentucky has the lowest overall cost of doing business in the Eastern United States.

"Kentucky is the third-largest manufacturing state for automobiles and light trucks in the United States," said Larry Hayes, Secretary of the Cabinet for Economic Development for the Commonwealth of Kentucky. "When people think of Kentucky, they think of bourbon and thoroughbred racing, not automobile companies in the Commonwealth."

While the automotive industry has a storied history within Kentucky, which includes Ford's first assembly plant in 1913, the home of General Motors' Corvette and Toyota's nearly 30-year presence, it is also expanding its presence. For example, Toyota's choice of Kentucky as the place to build its first U.S.-manufactured Lexus is part of a $563 million investment that will also add engine assembly lines at its sprawling Georgetown facility. But growth in the automotive industry today is dependent on hybrid technology, new battery platforms and alternative fuels. And this is where Kentucky is clearly taking the lead.

CHARGING AHEAD

Located within the Spindletop Research Campus in Lexington, the Kentucky-Argonne Battery Manufacturing R&D Center (Battery Center) opened its doors in August 2012. Established through a partnership between the Commonwealth of Kentucky, the University of Louisville, the University of Kentucky, and the Argonne National Laboratory, it is tasked with facilitating collaborations with industry, universities and federal labs to develop new battery technology.

"Gov. (Steve) Beshear was the driving force in bringing a federal research facility to Kentucky, and now we have a world-class facility that is becoming an economic engine for the entire region," said Dr. Tony Hancock, executive director of the Kentucky-Argonne Battery Center. "Working with Secretary (Leonard) Peters of the Energy and Environment Cabinet, they really put all the pieces together so we can push our agenda as far as we can."

Hancock said Gov. Beshear wanted an open-access facility that would attract smaller companies, and larger companies like Ford, GM and Toyota, to conduct research here. The Center's efforts at attracting new companies should only get easier.

The Battery Center is developing new technologies and new advanced manufacturing methods that will benefit a wide spectrum of industrial sectors, including powering tomorrow's automobiles and other modes of transportation; enabling stationary energy-storage systems to enhance our nation's electrical grid and keep mission-critical facilities up and running, and producing new types of electrochemical materials and components that will help improve everything from mobile phones to space vehicles.

"These are some of the foremost challenges facing today's scientists and engineers, and Kentucky is proud to play a vital role in finding solutions to help secure America's energy future," said Gov. Beshear. "Now, the Kentucky-Argonne Center is just over a year old, but it

Engineer Associate Victor Kunadian uses a glove box to keep organic electrolytes dry while working at the Kentucky-Argonne Battery Manufacturing Research and Development Center.

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is already having a significant impact on the Commonwealth's economy."

A number of entrepreneurial and innovative companies are using the Center, among them Angstron Materials out of Dayton, Ohio, which is working with nano graphene platelets. Another company working with nanoengineered materials, nGimat, a spinoff out of Georgia Tech, was one of the first companies to move to Kentucky as a result of the Center. Yet another company opened its doors this fall.

"In September, NOHMs Technologies announced it has chosen to move its R&D, product development and business operations from New York to Lexington to benefit from the expertise and equipment at the Kentucky-Argonne Center," said Gov. Beshear. "At the same time, NOHMs is planning to build in Kentucky an advanced research, product development and manufacturing facility to produce lithium-ion batteries for military, telecommunication and electric vehicle applications."

The company plans to create up to 162 jobs and invest more than $5.3 million in the project. Founded in October 2010, the company's vision is to commercialize lithium-sulfur battery technology that will revolutionize vehicle

"Kentucky is proud to play a vital role in finding solutions to help secure America's energy future."

Gov. Steve Beshear

markets, including everything from spacecraft to electric automobiles. The company believes its lithium-sulfur batteries can deliver enough energy at a cost low enough to allow mass commercialization of electric vehicles.

"This move will enable our company to take the next step to develop and commercialize our products across a variety of markets," said Nathan Ball, CEO of NOHMs. "We chose Kentucky because of the state's reputation for manufacturing and a talented workforce, strong support from the state for the battery and automotive industry and the facilities at KY-Argonne. We also benefit from a close relationship with the University of Kentucky's Center for Applied Energy Research, which has a long history in developing technology across many energy sectors."

Over the last 12 months, the Center has also developed research collaborations with other major corporations, among them Ford, Toyota and Hitachi. Certainly, the Battery Center is a fertile environment for the development of new battery technology. However, it wouldn't be possible without the Center's partnership with academia.

"Today celebrates new opportunities reached through partnership," said Eli Capilouto, president of the University of Kentucky, at the NOHMs news conference. "This announcement exemplifies the incredible possibilities unleashed when human capital, space and expertise combine with state and local entities to attract a new company, new technology and high-wage jobs to central Kentucky. It also underscores the importance of federal and state research and development support to pioneer innovations that transform industry and fuel economic growth."

SETTING A SCIENTIFIC AGENDA

While companies such as NOHMs are on the cutting edge of battery technology, they are as much concerned with being able to transition that technology to viable markets around the globe. And while the Battery Center is already attracting innovative scientists and companies, it has not yet reached critical mass when it comes to the science of new battery technology, said Dr. Mahendra Sunkara, director of the Conn Center for Renewable Energy Research at the University of Louisville and a collaborator with the Battery Center.

"In terms of the Battery Center, the state is interested in attracting companies," said Sunkara, "so the manufacturing research and development has to be tied strongly to the industry."

Eventually, schools such as the University of Louisville and the University of Kentucky will play a role in defining the scientific agenda at the Center. In the interim, both of the universities already are involved with battery research of their own.

"From a Conn Center perspective and our colleagues who are researchers on the University of Kentucky campus, we all want to work together on the next high-density durable energy storage technology," said Sunkara.

Currently, researchers at the Conn Center are working on improving the energy density and durability of lithium ion battery technology, using nano-wires to improve conductivity.

The Center is also working on lithium-sulfide technology as well as large-scale energy storage technologies that can be used to store renewable energies such as wind and solar and tie them back into the grid.

"We believe storage plays a central role in allowing these diverse power resources to be added to the grid," added Sunkara.

Research at the Conn Center, by the center's very definition, is not limited to battery technology. In terms of solar energy, the Conn Center is also working on thin film technology for use in solar power, establishing a process for roll-to-roll manufacturing of thin film solar cells on a flexible substrate.

But perhaps the most revolutionary work being performed at the Conn Center, as well as the University of Kentucky, is the use of solar radiation to separate hydrogen from water, cheaply and easily.

"We came up with a new material, a compound of gallium nitride that reduces the band gap from 3.5 EV down to 2.0 EV, which is perfect for solar use," said Sunkara. "Working with researchers from the University of Kentucky, we introduced antimony and created a new compound, and have patented it. We are now in the process of developing this new technology, improving it and optimizing it."

The alloy formed by a two percent substitution of antimony (Sb) in gallium nitride (GaN) has the right electrical properties to enable solar energy to split water molecules into hydrogen and oxygen. The components of the alloy, gallium nitride and antimony, are widely in the electronic industry. While gallium nitride is used to make bright-light LEDs, antimony has been used as metalloid element in the microelectronics industry.

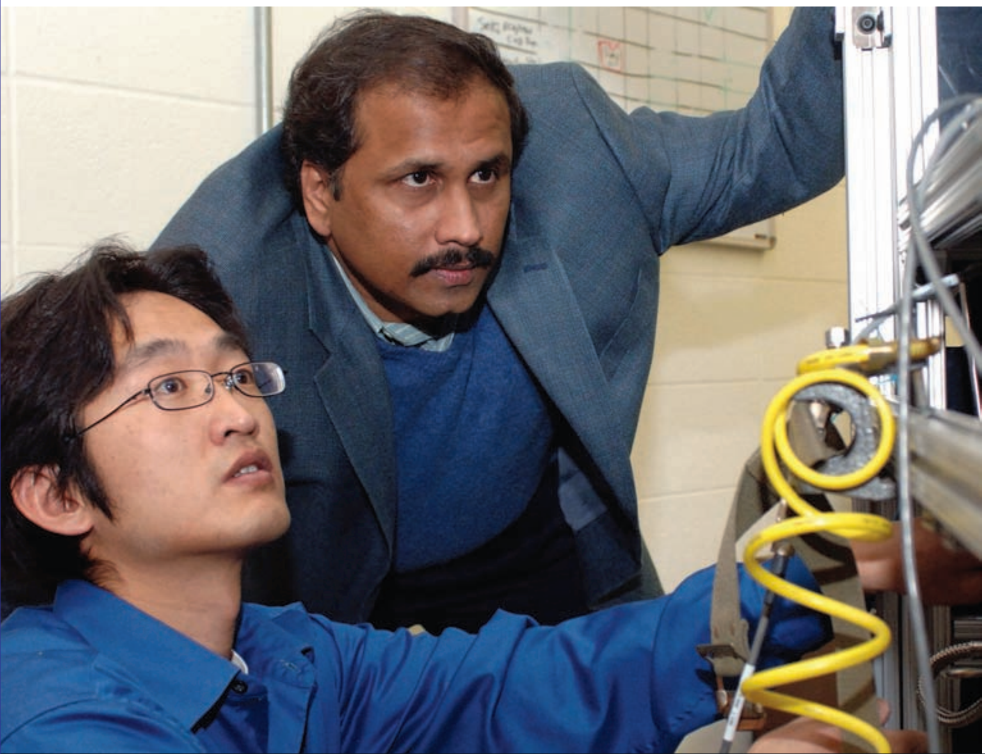
Much of the hydrogen available today is produced during the petrochemical refining process, "so even though hydrogen is a very clean energy carrier for fuel cells in a car or power sources for the home or business, you are still emitting CO_2 from the production source," Sunkara explained. "So if you use our process to produce hydrogen, two things happen. CO_2 emissions go down during production, and it will be easy for people to use. Even in your own home you will be able to produce hydrogen."

Tweaking a relatively inexpensive semiconductor to generate hydrogen from water using sunlight is revolutionary to say the least. It's bound to attract a wide variety of scientists to Kentucky to work in the industry.

"Another area of research that we are working on is the use of biomass and biofuels," added Sunkara.

"Kentucky is particularly well-suited for developing a biofuels industry," said Gov. Beshear. "In the east we have ample timber and forestry resources as well as the opportunity to grow energy crops on land reclaimed after mining operations.

"Elsewhere in the state, we have an enormous agricultural base for growing traditional crops like corn and soybeans, as well as new oil producing crops like canola – all of which can be used to produce biofuels."



LEFT: Dr. Mahendra Sunkara, director of the Conn Center for Renewable Energy Research works with a researcher at the University of Louisville.

BELOW: The CRAFT Center at Eastern Kentucky University is one of the Commonwealth's premier biofuel research centers.

The Center for Renewable & Alternative Fuel Technologies (CRAFT), at Eastern Kentucky University, is one of the premier organizations in the Commonwealth investigating the use of biomass and biofuels.

"We have concentrated on trying to convert biomass that can be grown locally to get the phototropic sugars produced during photosynthesis," explained Dr. Bruce Pratt, director of CRAFT. "Then we break those sugars out of biomass and use them. Yes, the sugars can be used for ethanol, but we have taken a little different twist."

In its research, CRAFT is using those sugars to grow heterotrophic algae. Capturing energy from sunlight in the plant materials allows the algae to be grown in a dark and controlled environment. As a part of the process, the algae produce oils which can then be extracted to create biodiesel or renewable jet fuels.

"A partnership between Eastern Kentucky University and General Atomics, a leader in energy research and defense manufacturing, is also very promising," added Gov. Beshear. "The program is studying a number of different sources of biomass that are high in cellulose. They are developing new methods of using enzymes to break down that cellulose and release the sugars it contains. Then they'll take those sugars and other nutrients and feed them to algae in large vats where the algae will grow and rapidly multiply – they are some of the fastest growing plants on Earth."

see blue.™
see tomorrow.
The University of Kentucky is one of a handful of universities in America with all the leading medical and professional colleges and programs on one, central campus. Combined with one of the country's fastest-growing medical centers, UK is uniquely positioned for the kind of interdisciplinary work that takes discoveries from the lab to communities to extend and enhance lives and bolster economies.
UK's health enterprise is one of only 23 in the country to receive three top federal designations for cancer, in aging and for clinical translational science. UK's College of Pharmacy is ranked number 5 in the country and is housed in the most advanced research and classroom space in the country.
The Coldstream Research Campus is a hub of innovation for biotechnology, pharmaceuticals, equine health and a variety of other industry sectors. Our Center for Applied Energy Research is a nationally recognized leader in clean coal and sustainable energy technologies and the Kentucky-Argonne Battery Manufacturing Research and Development Center is working to generate batteries that will power the next generation of more fuel-efficient cars.
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The specialized strains of algae grown in the highly-controlled heterotrophic environment are bio-engineered to have a very high oil content, so after the algae is harvested, the oil is extracted and can be converted into biodiesel. The U.S. Air Force has also worked with Eastern Kentucky University and General Atomics to develop and demonstrate bio-oil production processes to produce jet fuel from cellulosic feedstocks.

There are several companies and educational institutions in the state that are currently researching the use of heterotrophic algae on everything from aquaculture to producing nutrient supplements for feed stocks.

The results just may be the answer to feeding the nine billion people expected on our planet by mid-century.

FEEDING THE WORLD

Producing enough food resources to feed the world's seven- billion-plus inhabitants is already a major problem for agriculturists, aquaculturists, farmers and food producers. Now, factor in an additional two billion or more mouths to feed by 2050, and it's a situation that would appear, at least on the surface, to be perilous.

While famine and hunger are already extracting a needless, but grim toll on the world's population, there are universities and companies working to solve the problems of world hunger. Some of the more innovative are in Kentucky.

Not too surprisingly, the answer to solving the world's hunger problems, and perhaps even improving overall human health, starts at the very base of the food chain with one of the most diverse and prolific forms of life on the planet: algae.

"Within aquaculture, our average annual growth rate is 6.3 percent, and that is the fastest growing sector of food production in the world," said Vaun Cummins, senior aquaculturist at Alltech, a global biotech company headquartered in Nicholasville, Kentucky, that develops natural feed supplements for agriculture and aquaculture. "Capture fisheries at this point in time, and even for the past five or ten years, have become relatively static. Many of their traditional areas are overfished and over-exploited.

"So today you are seeing a very strong reliance on aquaculture," added Cummins. "In fact, 47 percent of the fish consumed today is supplied by aquaculture."

For the foreseeable future, aquaculture is poised to grow at a rate that keeps it abreast of the world's explosive population growth, yet the industry is facing its own food shortages.

"While aquaculture is one of the only food production industries that is outpacing world population growth, there is still a great reliance within aquaculture on marine resources and marine nutrition input between fish meal and fish oil," said Cummins. "Although within the last 10 to 20 years there have been major advances in fish meal and fish oil replacement, substitution and reduction in aquaculture diets, the overall expansion of the industry has led to an increase in the quantity of fish meal and fish oil that has been utilized."

Researchers at the CRAFT Center at Eastern Kentucky University extract oils from algae to produce renewable diesel and jet fuels.

Exploring every angle in science and technology

Kentucky stays ahead of the curve by exploring every angle in scientific and technological innovation. From world-class research facilities to high-tech startups, Kentucky is opening eyes.

The University of Louisville's Level 3 BioSafety Lab specializes in live imaging of infectious diseases and identifying new therapeutics and vaccines. The University of Kentucky's Center for Applied Energy Research is developing biofuels from switchgrass and algae. Western Kentucky University's large-chamber SEM performs nondestructive analysis of objects up to 650 pounds.

The Kentucky-Argonne Battery Manufacturing R&D Center is one of the first federal-state labs developing energy storage and battery production technologies.

High-tech companies also flourish here. Coldstream Laboratories formulates and produces sterile pharmaceuticals. Kentucky BioProcessing makes plant-based proteins from modified crops under cGMP conditions.

Kentucky also supports entrepreneurs and companies with incentives, such as our SBIR-STTR Matching Funds Program, which has awarded over $40 million to 87 companies, including 28 firms that moved from other states.

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Kentucky
UNBRIDLED SPIRIT™
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At Alltech Algae, researchers grow and evaluate algae grown under heterotrophic conditions, allowing greater control of the finished product.

COURTESY OF ALLTECH

Of course, fish meal and fish oil are very important for a piscatorial diet, if you want the farm-raised fish to have copious amounts of the fatty acids such as Omega 3s and DHA that are so important to the diet of both the fish and the humans who consume them.

But there is a conundrum. As aquaculture grows to the point where it supplies the world population with over 50 percent of its fish, it won't be able to rely on either over-fished marine resources or land-based feedstocks such as soybean meal because there is only about six percent of arable land left on earth. And it's being used up quickly.

On the surface, that makes aquaculture unsustainable.

"That's why one of the alternatives we are looking at is algae," said Cummins.

Founded with just $10,000 of capital in 1980 in Lexington, Kentucky, Alltech today is fast becoming a $1 billion company focused on providing natural solutions to the food and feed industries. The company acquired an algae producing facility, establishing Alltech Algae in 2011, which is considered to be one of the largest commercial algae production sites in the world.

Many educational institutions, scientists and companies like Alltech are now looking to algae as an answer to providing food sources for aquaculture and nutritional supplements to terrestrial feedstocks. Since they are aquatic, algae grow much faster than land plants because they do not need to expend energy growing roots and support structures like trunks, leaves and stems. Without the need for support, algae can triple or quadruple their biomass every day.

Indeed, algae are the only biomass material that allows production with daily harvests all year round. One acre of algae can produce the same amount of protein in a year as 21 acres of soybeans or 49 acres of corn, thus freeing that acreage up for human rather than animal consumption.

While most commercial production of algae is done autotrophically, the algae grown by Alltech is grown heterotrophically, allowing the company to manipulate the nutrients fed to the algae to achieve desired nutrients or traits from the yield.

By manipulating the physical and chemical properties of the cultural medium, several species of microalgae can overproduce and accumulate higher levels of specific fatty acids. Xu et. al (2006) demonstrated that C. protothecoides had a lipid content as high as 55 percent, approximately four times greater than when grown autotrophically. In another study, Barclay et. al (1994) showed that omega-3 fatty acid productivity was two to three times higher when produced in heterotrophic rather than autotrophic conditions.

This all bodes well for the terrestrial feed and aquaculture industries, but the work is ongoing. To that end, Alltech has aligned itself with major educational institutions not only in Kentucky, but from around the world.

LEFT: Epidural stimulation patient Rob Summers is able to stand up at the Kentucky Spinal Cord Injury Research Center at the University of Louisville.

ALLIANCE WITH EDUCATION

Last year, Alltech forged a master alliance with the University of Kentucky for science and economic development within the state. While the company and school have always enjoyed a long and deep collaborative relationship on a wide range of projects, the new master agreement will help generate annual funding for research of activities that is expected to grow to more than $5 million annually by its third year.

Alltech also entered into an alliance with Kentucky State University earlier this year that focuses on modern sustainable farming techniques. Obviously, the agriculture industry will require major technological leaps in order to keep pace with the growing population, while still preserving natural resources for future generations. The joint research alliance between the company and Kentucky State University is designed to develop those sustainable farming techniques and modern farming models.

"We're excited about the collaboration between Alltech and Kentucky State University," said Dr. Mary Evans Sias, Kentucky State University's president. "KSU's world-class aquaculture program combines innovative research and outreach to assist farms and families. Alltech is a major global corporation that focuses its resources on the sustainability of the planet. We can only expect great things to come from this perfect match."

The Alltech-KSU Sustainable Farming Alliance will be managed by three Alltech scientists, and chaired by Dr. Teferi Tsegaya, dean of KSU's College of Agriculture, Food Science and Sustainable Systems and associate vice president for land grants.

While creating sustainable aquaculture and agricultural systems to help feed the world's burgeoning population is obviously a noble cause, it's only one aspect of the research going on in Kentucky with algae. Using the heterotrophic growing process, Alltech is also working with educational institutions across the state to create nutritional supplements that can be researched for potential cures or preventative measures in the fight against diseases such as diabetes and Alzheimer's disease. And the results are promising.

But none of this work would be possible without the spirit of cooperation and the open lines of communication between industry, the state government and educational institutions that exist within the state.

When you have everyone in the Commonwealth pulling in the same direction, it can expand your horizons well beyond creating tomorrow's alternative fuel resources, or feeding the world's population.

STIMULATING ACTIVITY FOR THE FUTURE

One of the more innovative research projects to come out of the Commonwealth is the work of Susan Harkema Ph.D., the rehabilitation research director of the Kentucky Spinal Cord Injury Research Center at the University of Louisville. Led by Scientific Director Scott R. Whittemore, Ph.D., who is committed to further developing it into a world-class scientific and clinical research center, the Kentucky Spinal Cord Injury Research Center is in a rapid growth phase, made possible by funding and excellent cooperation between the State of Kentucky, University of Louisville and Norton Healthcare, and a recent $5.5 million grant from the National Institutes of Health.

Working with paraplegic and quadriplegic patients who suffered spinal cord injuries, Harkema has developed a means of electronic stimulation of the spinal cord that in effect, may train the spinal cord to relearn or remember basic functions like bladder and bowel control, all the way up to voluntary movements like standing and even walking with assistance.

"We're implanting an electrode in the lower lumbosacral spinal cord in individuals with spinal cord injury during locomotor training," she said.

This allows for electric stimulation of the spinal cord, with the goal of restoring movement or regaining some non-voluntary functions. Of the four patients involved in the study, three have had very positive outcomes.

"And the fourth hasn't been in the study long enough to have had a positive outcome as yet," Harkema said. "The remarkable finding is that when the stimulator is off they are completely paralyzed and can't move their legs.

"However, when the stimulator is on, when they plan to move their toes they can move them. And when they plan to bend their knees they can bend them."

While the future looks bright, Harkema stressed that the research is still in its nascent stages and much more clinical work and evaluation needs to be done.

"I don't like to use the word 'cure' because it means a lot of different things to a lot of different people," she said. "Some people might look upon a cure as complete regeneration of the spinal cord, where others might see a cure as regaining all the functions they had prior to the injury. Still others might see regaining temperature control in their limbs or regaining use of bowel or bladder functions.

"What we are saying is that this is a victory over paralysis. That we are doing something that is moving us in the right direction. All of our patients have been able to stand, for instance. One of our subjects was actually able to stand and put his arm around his dad. And this was something that before now, was not in anybody's hypothesis or expectations."

"The Spinal Cord Injury Research Center was actually created as a matter of public policy by the Commonwealth of Kentucky," said Dr. James Richard Ramsey, president of the University of Louisville. "The research being done at the University of Louisville is internationally recognized for its success in locomotive training and epidural stimulation. This is an important area to the University because it is one of those areas where we can indeed truly be premier, not just nationally, but internationally."

LAUNCHING PAD FOR NEW TECHNOLOGIES

Dedicated to innovation, the Commonwealth of Kentucky is home to some unique organizations, among them the Kentucky Science and Technology Corporation (KSTC). A private, non-profit corporation committed to the advancement of science, technology and innovative economic development, the KSTC works with private companies, researchers, educators and state and national government agencies to enhance the ability to develop and apply science to the marketplace. At its annual IdeaFestival held in Louisville, the organization brings together innovative and creative thinkers from diverse disciplines such as dance, entertainment, gaming and science.

"The idea being that we expose creative thinkers to some new ideas in other areas," said Kris Kimel, founder of the IdeaFestival and president of the KSTC. "We also feel that a lot of game changing innovation happens at the intersections of different disciplines, from science and the arts to design, business and philosophy. That is what the IdeaFestival is all about."

Through one of its wholly owned subsidiaries, Kentucky Space, the KSTC is working on a revolutionary and interesting entrepreneurial endeavor in space called ExoMedicine.

"What we uncovered was that an understanding of how living systems and disease processes operate outside the force of gravity is basically still an undiscovered area of medicine," said Kimel. "Most work on medicine in space has been connected to astronaut health. But there are only four forces in nature. When you take one of them [gravity] away, you start to see changes happen at the genetic and cellular level that could not have been predicted."

"We have the ability to reach the world in a very timely fashion with products made in Kentucky."

Sec. Larry Hayes

By increasing further understanding of what happens in space, Kentucky Space hopes to accelerate a deeper understanding of new applications and interventions that could change the profile of some medical treatments, whether that be through new pharmaceuticals or new tissues that have been developed in the microgravity of space.

"In fact, we just got approved for a regenerative medicine experiment on the International Space Stations next year, partnering with Tufts University," added Kimel.

The Center for the Advancement of Science in Space, which was selected by NASA in July 2011 to maximize use of the International Space Station U.S. National Laboratory, recently announced an agreement with Kentucky Space LLC to facilitate biomedical research on the ISS. Dr. Mahendra Jain, principal investigator for Kentucky Space, has proposed an experiment to study regeneration in planarians, which are flatworms capable of rebuilding body organs and nervous systems after damage.

In partnership with Dr. Michael Levin of Tufts University, Dr. Jain will examine the effects of the space environment on these enhanced healing abilities. Gravity, or the lack thereof, influences the way cells behave and their ability to rebuild tissue.

Studying planarians in space may reveal new aspects of how cells rebuild tissue, which could lead to breakthroughs in medical treatments for humans. For example, regenerative medicine has the potential to treat conditions like Parkinson's, heart disease, and lost limbs. While innovation and development in Kentucky are certainly diverse, there is an underlying element of cooperation that permeates many of the Commonwealth's scientific endeavors.

"One of the most important components of a technology-based economy is the strength of its research and development institutions," said Gov. Beshear. "R&D drives technological progress, which leads to new products, new companies and new jobs – and, therefore, to more economic growth."

"We've seen from some of the nation's early university-industry centers that building a research base does not automatically result in commercialization," added Gov. Beshear. "For a state or region to capitalize on its 'technology generators,' such as our research universities, there must be mechanisms that move innovation into the marketplace. That's why we've had in place, for over a decade now, our Kentucky Innovation Network."

Consisting of 12 Innovation and Commercialization Centers across the Commonwealth, this Network is staffed by experienced and educated business experts who offer their services – for free – to help develop Kentucky's innovation-driven, technology-based companies. Since 2002, the Network has assisted nearly 1,300 companies that have generated in excess of $3 billion in revenues and created nearly 3,000 high-tech jobs with annual salaries averaging above $55,000.

In the Commonwealth of Kentucky, it's not just about communication, but also connecting and cooperating.

"Partnerships for the sake of claiming partnerships will not be effective," said Dr. Ramsey. "We partner with healthcare delivery companies, drug companies and others. Definitely, there is a point where these partnerships become not two separate organizations working together, but one entity working for a single goal."

"We have the ability to reach the world in a very timely fashion with products made in Kentucky," said Sec. Hayes.

"Business is not just about communication, but also connections," added Dr. Pearse Lyons, founder and president of Alltech. "In a smaller state like Kentucky, you know the governor, you know the powers that be, you know who makes things happen and who doesn't. Any time you can take communication and turn it into a connection, you can really make things happen."

And right now there are a lot of things happening in the Commonwealth of Kentucky.


STIMULATING SPINAL CORD MEMORY
CREATING UNFORGETTABLE MOMENTS OF
RECOVERY
See how UofL Professor and '09 Reeve-Irvine Research Medal recipient, Susan J. Harkema, PhD, is conducting promising research on human locomotion after neurologic injury and training the spinal cord to "remember" how to walk.
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INNOVATION

WORLD CHANGING IDEAS

10 ways science may jazz up our gadgets, help to solve our most intractable problems and save lives

Scientific advances can be smart, tantalizing, bizarre—and still never make it out of the lab. To change the world, a new idea must have a path from drawing board to practical products and manufacturing processes: in the parlance of Silicon Valley, it must "scale." Nobody can predict the future, but each of the 10 breakthroughs on the following pages has the potential to make it big. We begin with a full-length article on a new way to design materials atom by atom, using supercomputers and the equations of quantum mechanics, which could take much of the perspiration out of innovation (*page 36*). We continue with a fast-paced look (*page 41*) at "metamaterials" that promise cell phones as thin as credit cards; genomic therapies that turn ordinary gut microbes into weapons against disease; planes and bridges made of ultralight pieces that snap together like Legos; an antiseptic that could prevent 500,000 infant deaths a year; and other good ideas. Look for them in the years ahead. —*The Editors*

Illustrations by Marek Haiduk

WORLD CHANGING IDEAS

MATERIALS SCIENCE

THE STUFF OF DREAMS

With supercomputers and the equations of quantum mechanics, scientists are designing new materials atom by atom, before ever running an experiment

By Gerbrand Ceder and Kristin Persson

In 1878 Thomas Edison set out to reinvent electric lighting. To develop small bulbs suitable for indoor use, he had to find a long-lasting, low-heat, low-power lighting element. Guided largely by intuition, he set about testing thousands of carbonaceous materials—boxwood, coconut shell, hairs cut from his laboratory assistant's beard. After 14 months, he patented a bulb using a filament made of carbonized cotton thread. The press heralded it as the "Great Inventor's Triumph in Electric Illumination." Yet there were better filament materials. At the turn of the century, another American inventor perfected the tungsten filament, which we still use in incandescent lightbulbs today. Edison's cotton thread became history.


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Gerbrand Ceder is a professor of materials science and engineering at the Massachusetts Institute of Technology. Along with Kristin Persson, he is a co-founder of the Materials Project, which provides computed materials property data to the research community.

Kristin Persson is a staff scientist at Lawrence Berkeley National Laboratory. She obtained her Ph.D. in theoretical physics at the Royal Institute of Technology in Stockholm.

Materials science, the process of engineering matter into new and useful forms, has come a long way since the days of Edison. Quantum mechanics has given scientists a deep understanding of the behavior of matter and, consequently, a greater ability to guide investigation with theory rather than guesswork. Materials development remains a painstakingly long and costly process, however. Companies invest billions designing novel materials, but successes are few and far between. Researchers think of new ideas based on intuition and experience; synthesizing and testing those ideas involve a tremendous amount of trial and error. It can take months to evaluate a single new material, and most often the outcome is negative. As our Massachusetts Institute of Technology colleague Thomas Eagar has found, it takes an average of 15 to 20 years for even a successful material to move from lab testing to commercial application. When Sony announced the commercialization of the lithium-ion battery in 1991, for example, it seemed like a sudden, huge advance—but in fact, it took hundreds or thousands of battery researchers nearly two decades of stumbling, halting progress to get to that point.

Yet materials science is on the verge of a revolution. We can now use a century of progress in physics and computing to move beyond the Edisonian process. The exponential growth of computer-processing power, combined with work done in the 1960s and 1970s by Walter Kohn and the late John Pople, who developed simplified but accurate solutions to the equations of quantum mechanics, has made it possible to design new materials from scratch using supercomputers and first-principle physics. The technique is called high-throughput computational materials design, and the idea is simple: use supercomputers to virtually study hundreds or thousands of chemical compounds at a time, quickly and efficiently looking for the best building blocks for a new material, be it a battery electrode, a metal alloy or a new type of semiconductor.

Most materials are made of many chemical compounds—battery electrodes, which are composites of several compounds, are good examples—but some are much simpler. Graphene, which has been widely hyped as the future of electronics, consists of a one-atom-thick sheet of carbon. Regardless of a material's complexity, one thing is always true: its properties—density, hardness, shininess, electronic conductivity—are determined by the quantum characteristics of the atoms of which it is made. The first step in high-throughput materials design, then, is to virtually "grow" new materials by crunching thousands of quantum-mechanical calculations. A supercomputer arranges virtual atoms into hundreds or thousands of virtual crystal structures. Next, we calculate the properties of those virtual compounds. What do the crystal structures look like? How stiff are they? How do they absorb light? What happens when you deform them? Are they insulators or metals? We command the computer to screen for compounds with specific desirable properties, and before long, promising compounds rise to the top. At the end of the process, data generated during that investigation go back into a database that researchers can mine in the future.

Since 2011 we have been leading a collaboration of researchers that aims to accelerate the computer-driven materials revolution. We call it the Materials Project. The goal is to build free, open-access databases containing the fundamental thermodynamic and electronic properties of all known inorganic compounds. To date, we have calculated the basic properties (the arrangement of the crystal structure, whether it is a conductor or an insulator, how it conducts light, and so on) of nearly all of the approximately 35,000 inorganic materials known to exist in nature. We have also calculated the properties of another few thousand that exist only in theory. So far some 5,000 scientists have registered for access to the database containing this information, and they have been using it to design new materials for solar cells, batteries, and other technologies.

We are not the only ones pursuing this approach. A consortium of researchers led by Stefano Cortarolo of Duke University has calculated tens of thousands of alloy systems; their research could yield lighter, stronger car frames, structural beams for skyscrapers, airplane skins, and so on. The Quantum Materials Informatics Project, which consists of researchers at Argonne National Laboratory, Stanford University and the Technical University of Denmark, has been using high-throughput computing to study catalytic processes on metal surfaces, which is particularly useful in energy research.

In the very near future, materials scientists will use high-throughput computing to design just about everything. We believe that this will lead to technologies that will reshape our world—breakthroughs that will transform computing, eliminate pollution, generate abundant clean energy and improve our lives in ways that are hard to imagine today.

THE MATERIALS GENOME

THE MODERN WORLD is built on the success of materials science. The advent of transparent, conductive glass led to the touch screens on our smartphones. The reason those phones can

IN BRIEF

Engineered materials such as chip-grade silicon and fiber-optic glass underpin the modern world. Yet designing new materials has historically involved a frustrating and inefficient amount of guesswork.

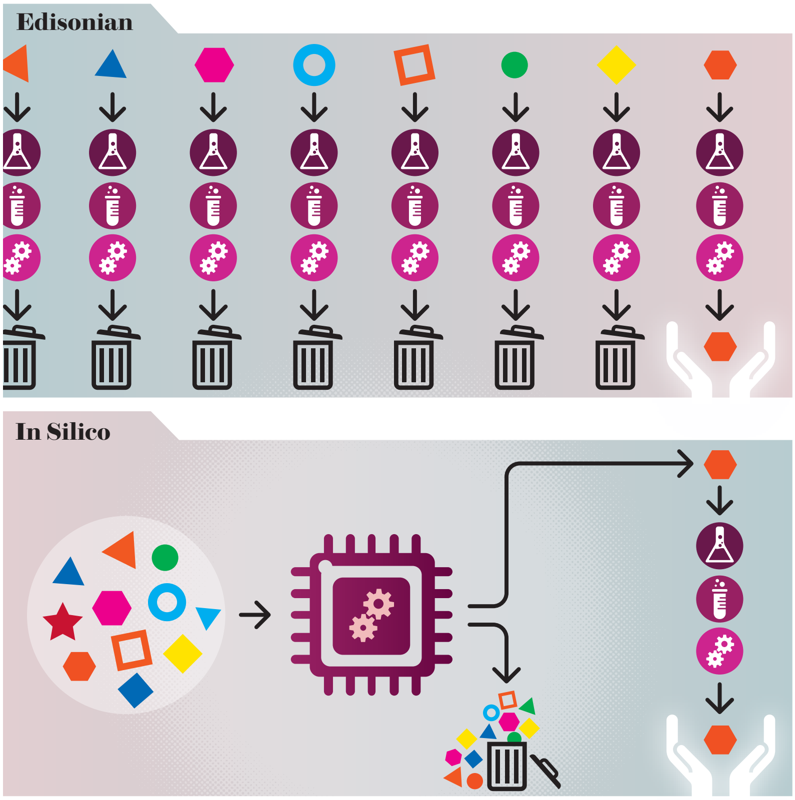
Streamlined versions of the equations of quantum mechanics—along with supercomputers that, using those equations, virtually test thousands of materials at a time—are eliminating much of that guesswork.

Researchers are now using this method, called high-throughput computational materials design, to develop new batteries, solar cells, fuel cells, computer chips, and other technologies.

BASICS

What a Difference a Supercomputer Makes

Roughly speaking, the Edisonian method of materials design consists of testing everything you can think of and throwing away what does not work. With high-throughput computational materials design, researchers can quickly screen candidates in silico—virtually, on giant supercomputing banks—saving time and money and preventing frustration. Once the computer has tested hundreds or thousands of materials and produced a list of the top 10 or so candidates, researchers begin synthesizing physical samples and testing them with conventional laboratory methods.



beam information around the world at the speed of light is that materials scientists found a way to make glass free of impurity ions, enabling fiber-optic communications. And the reason those phones last a full day on a charge is because in the 1970s and 1980s, materials scientists developed novel lithium-storing oxide materials—the basis for the lithium-ion battery.

It was our work on batteries that brought us to high-throughput materials design in the first place. We had spent our careers doing computational materials design, but until a 2005 conversation with executives from Proctor & Gamble (P&G), we did not think about what serious time on the world's most powerful supercomputers could make possible. These P&G executives wanted to find a better cathode material for the alkaline batteries made by their Duracell division. They asked us a surprising question: Would it would be possible to computationally screen *all known compounds* to look for something better? On reflection, we realized that the only real obstacles were computing time and money. They were happy to supply both. They committed $1 million to the project and gave our small team free rein over their supercomputing center.

We called our effort the Alkaline Project. We screened 130,000 real and hypothetical compounds and gave P&G a list of 200 that met the criteria the company asked for, all of which had the potential to be significantly better than its current chemistry. By then, we were convinced that high-throughput materials design was the future of our field. We added staff, raised resources and, in 2011, launched a collaboration between M.I.T. and Lawrence Berkeley National Laboratory, which we initially called the Materials Genome Project. Teams at the University of California, Berkeley, Duke University, the University of Wisconsin–Madison, the University of Kentucky, the Catholic University of Leuven in Belgium and other institutions have since joined in the effort, all of them contributing the data they generate to our free, open-access central data repository at Lawrence Berkeley.

Before long, we dropped "Genome" from the project name to distinguish it from an initiative that the White House Office of Science and Technology Policy was launching. And to be fair, the properties of chemical compounds are not really "genes"—they are not hereditary bits of information that provide a unique sequence of data. Still, a direct relation exists between the function or property of a material and its fundamental descriptors. Just as blue eyes can be correlated to a certain gene, the electronic conductivity of a material, for example, can be traced back to the properties and arrangements of the elements it is composed of.

These kinds of correlations are the basis of materials science. Here is a simple example: we know we can "tune" the color of minerals by introducing targeted defects into their crystal structure. Consider the ruby. Its red hue comes from an accidental 1 percent substitution of a chromium ion (Cr^{3+}) for aluminum in the common mineral corundum (Al_2O_3). When the Cr^{3+} is forced into this environment, its electronic states become altered, which changes the way the material absorbs and emits light. Once we know the origin—the fundamental descriptor—of a property (in this case, the redness of a ruby), we can target it with synthetic methods. By tweaking those chemical defects, we can design new synthetic rubies with perfectly tuned colors.

The equations of quantum mechanics can tell us how to do that tweaking—what elements to use and how to arrange them. Yet the equations are so complex that they can really only be solved by computer. Say you want to screen a group of

Illustration by Arno Ghelfi

a few hundred compounds to see which ones have the properties you need. It takes an incredible amount of computing power to crunch those equations. Until recently, it simply was not possible, which is why so much of materials science has historically proceeded by trial and error. Now that we have the computing power, however, we can finally take advantage of the full predictive potential of quantum mechanics.

Suppose we are researching thermoelectric materials, which generate an electric current if they experience a large temperature gradient. (The reverse is also true: a thermoelectric material can sustain a temperature difference if you run a current through it; think instant cooling.) Society wastes an enormous amount of heat through combustion, industrial processing and refrigeration. If we had efficient, cheap and stable thermoelectric materials, we could capture this heat and reuse it as electricity. Thermoelectric devices could transform industrial waste heat into electricity to power factories. Heat from car exhaust pipes could power the electronics in the cockpit. Thermoelectrics could also provide on-demand solid-state cooling: little devices that we could weave into our clothing that, with a flip of a switch, would cool us down, no fans or compressors required.

One of the best thermoelectrics we know of today is lead telluride, which is far too toxic and expensive to use commercially. Suppose you are a researcher looking for a better thermoelectric material. Without high-throughput computing, this is how it would go: You would start by looking for known compounds that, like lead telluride, have a high Seebeck coefficient (a measure of the amount of electricity you get out for the temperature difference that goes in) but that, unlike lead telluride, are not made of rare, toxic or expensive elements. You would pore over tables and compare numbers. If you were lucky, you would come up with some candidate chemistries that, in theory, would seem like they could work. Then you would make those compounds in a lab. Physically synthesizing materials is an expensive, time-consuming and difficult job. Generally, you have no idea going in whether the new material will even be stable. If it is, you can measure its properties only after you have synthesized the compound and then repeated the process until you have a fairly pure sample. This can take months for each compound.

So far researchers have had no luck finding alternative thermoelectric materials. But they have not yet tried high-throughput computational materials design. That will soon change. Starting this year, we will begin working with researchers at the California Institute of Technology and five other institutions to perform high-throughput searches for new thermoelectric materials. We intend to keep at it until we find the chemical compounds that could make those energy-saving, miracle-cooling technologies a reality.

THE GOLDEN AGE OF MATERIALS DESIGN

OUR ABILITY TO ACCESS, search, screen and compare materials data in an automated way is in its infancy. As this field grows, what could it yield? We will venture a few guesses.

Many promising clean-energy technologies are just waiting for advanced materials to become viable. Photocatalytic compounds such as titanium dioxide can be used to turn sunlight and water into oxygen and hydrogen, which can then be processed into liquid fuels. Other photocatalysts can do the same thing with carbon dioxide. The dream is an "artificial leaf" that can turn sunlight and air into methanol-like liquid fuels we could burn in cars and airplanes [see "Reinventing the Leaf," by Antonio Regalado; Scientific American, October 2010]. Researchers at the Joint Center for Artificial Photosynthesis, a U.S. Department of Energy research center, are using high-throughput methods to look for materials that could make this technology feasible.

What about finding new metal alloys for use in those cars and airplanes? Reducing a vehicle's weight by 10 percent can improve its fuel economy by 6 to 8 percent. U.S. industry already pours billions of dollars every year into research and development for metals and alloy manufacturing. Computer-guided materials design could multiply that investment. Significant advances in high-strength, lightweight and recyclable alloys would have a tremendous impact on the world economy through increased energy efficiency in transportation and construction.

Computing is another field in need of transformative materials. Recently we have seen many serious predictions that we are nearing the end of Moore's law, which says that computing power doubles roughly every two years. We have long known that silicon is not the best semiconductor. It just happens to be abundant and well understood. What could work better? The key is to find materials that can quickly switch from conducting to insulating states. A team at U.C.L.A. has made extremely fast transistors from graphene. Meanwhile a group at Stanford has reported that it can flip the electrical on/off switch in magnetite in one trillionth of a second—thousands of times faster than transistors now in use. High-throughput materials design will enable us to sort through these possibilities.

This list is much longer. Researchers are using computational materials design to develop new superconductors, catalysts and scintillator materials. Those three things would transform information technology, carbon capture and sequestration, and the detection of nuclear materials.

Computer-driven materials design could also produce breakthroughs that are hard to imagine. Perhaps we could invent a new liquid fuel based on silicon instead of carbon, which would deliver more energy than gasoline while producing environmentally benign reaction products such as sand and water. People have talked about the idea for decades, but no one has figured out a workable formula. High-throughput materials design could at least tell us if such a thing is possible or if we should focus our efforts elsewhere.

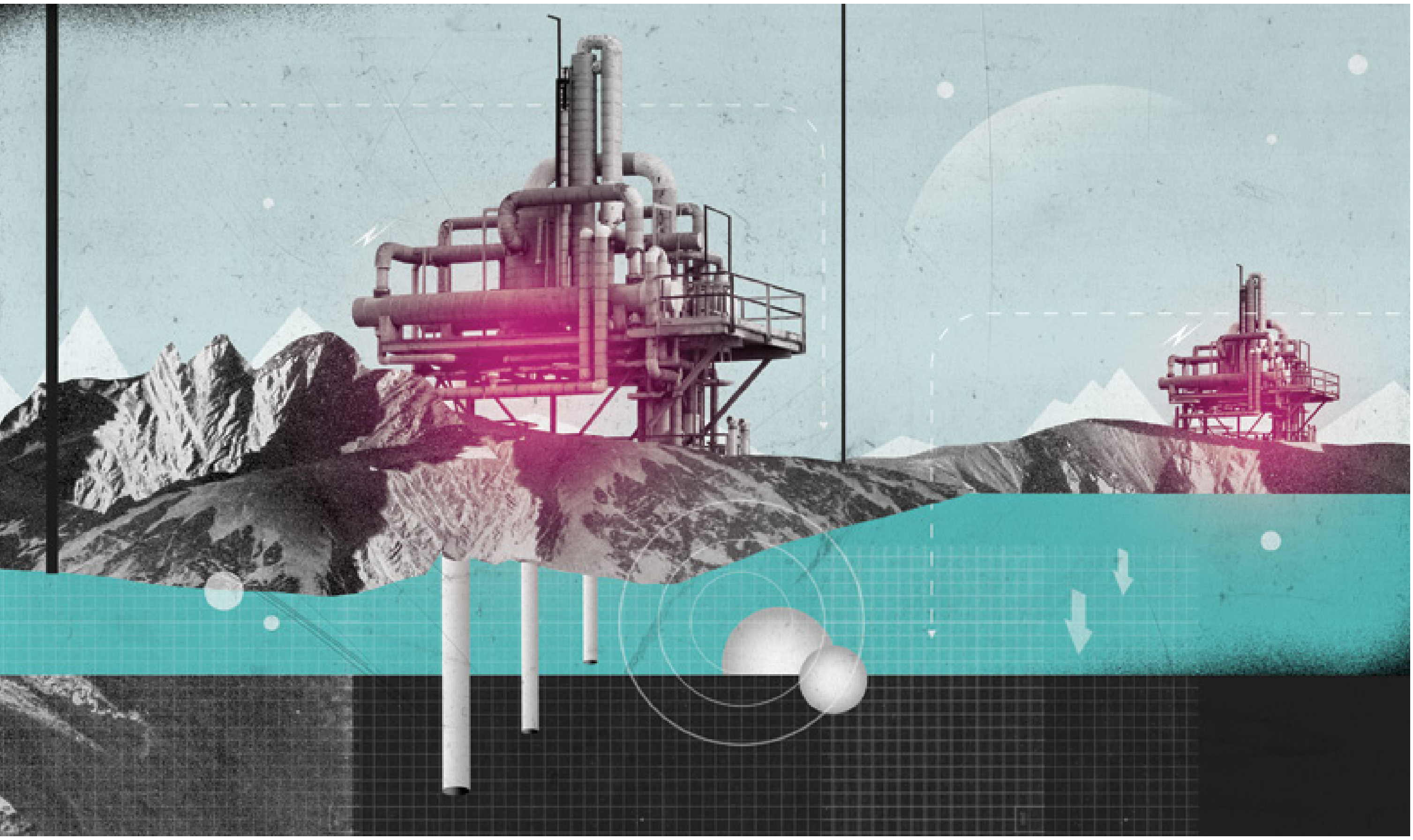
All of this is why we believe we are entering a golden age of materials design. Massive computing power has given human beings greater power to turn raw matter into useful technologies than they have ever had. It is a good thing, too. To help us deal with the challenges of a warming, increasingly crowded planet, this golden age cannot start soon enough. SA

MORE TO EXPLORE

Opportunities and Challenges for First-Principles Materials Design and Applications to Li Battery Materials. Gerbrand Ceder in *MRS Bulletin,* Vol. 35, No. 1, pages 693–701; September 2010.

The Materials Project: A Materials Genome Approach to Accelerating Materials Innovation. Anubhav Jain et al. in *APL Materials,* Vol. 1, No. 1; July 2013.

SCIENTIFIC AMERICAN ONLINE
To see a slide show of materials and the atomic properties that make them behave the way they do, go to **ScientificAmerican.com/dec2013/materials**



CARBON STORAGE

Turning CO_2, pumped underground, into stone

WHAT IF there was an easy way to take the carbon dioxide from coal power smokestacks and turn it back into a rock that would sit quietly, deep below the earth's surface? That would get around a key sticking point of current carbon storage schemes, which entail injecting CO_2 into porous sedimentary rock formations such as sandstone—that the gas could eventually escape, seeping back up to the surface and into the atmosphere, heating the planet.

Basaltic rock, which makes up part of the earth's crust, could be an alternative to sedimentary structures. Minerals within basalt, including magnesium, calcium and iron, gradually react with CO_2 to form carbonate crystals inside the pores and seams of basalt, entombing the carbon as a permanent solid. This process, known as enhanced weathering, could capture massive amounts of CO_2. Engineers are now trying to turn this bit of chemistry into practice.

This summer near Wallula, Wash., engineers injected almost 1,000 metric tons of CO_2 into layered basalt more than 800 meters belowground. For the next year they are monitoring how quickly and extensively those carbonate crystals appear. Some scientists have presumed that the process takes millennia to occur naturally, but laboratory results suggest it can occur in less than a decade. "It's not 1,000 years—it's not even several centuries," says Pete McGrail, an environmental engineer at Pacific Northwest National Laboratory, which oversees the project. "We're talking a few years to a few decades to complete the mineralization." That is quick enough to make a difference in the fight against global warming. Researchers expect to know more in December, when they have their first drill samples.

Engineers at a second project in Iceland, known as CarbFix, are injecting 1,500 tons of CO_2 over two years. They plan to pull samples in May and June 2014 and will continue monitoring through next December, according to Juerg Matter, a researcher at Columbia University who is involved with the work.

Some scientists are skeptical about whether the carbonate minerals are as leak-proof as hoped. Susan Hovorka, a geologist and carbon-sequestration expert at the University of Texas at Austin, says in certain conditions water deep below the surface could flow across the carbonate crystals and dissolve out the CO_2, allowing the gas to possibly seep to the surface. Testing will be needed, she notes, to determine how well basalt will retain the carbon.

The primary obstacle to carbon storage is policy rather than technical know-how, McGrail says. Without some economic incentive to sequester CO_2 in this (or any) fashion, the practice is unlikely to spread. Still, if the pilot projects offer proof that the gas can be locked underground and policy makers follow with a tax on carbon, basalts could provide a viable storage option. About a quarter of India's many coal-fired power plants sit atop a huge basaltic formation known as the Deccan Traps. If basalt can put our global warming villain back from whence it came, there's a whole lot of CO_2 ready to rock. —*Dave Levitan*

ULTRALIGHTS

Lego-like composites snap into place to make superstrong, affordable structures

Researchers turned off the Massachusetts Institute of Technology wind tunnel last year, satisfied with the most recent tests of a tough, new, ultralight composite material: a flexible, meshlike substance that snaps together like Lego bricks or K'nex. These pieces can be assembled to form 3-D chain mail–like structures that are 10 times stiffer for a given weight than existing ultralight materials. The researchers were testing how prototype airfoils and wing structures made of these new materials flexed and deformed in the strong air currents. Their dream of lighter yet more durable airplanes, spacecraft, even bridges made from snap-together parts had taken a major step forward.

This fundamentally different approach to devising materials could lead to incredibly lightweight and strong structures for aerospace, industrial and consumer products. The design is inspired by lattices in spongy bone that give animal skeletons strength at low weight. The composite could also overcome limitations in how large ultralight structures can be, imposed by conventional fabrication techniques.

Composites are typically built up with layers of molded fiber sheets slathered in resin. A heat-curing process hardens the resin, setting the desired shape. Manufacturing large structures requires huge, cylindrical ovens that bake big parts, which are later riveted together into a larger whole. The M.I.T. material could be made into an entire large object—such as an airplane fuselage—without rivets. Each piece of material would be linked to the next to create a full assembly. The bits could also be unlinked, allowing a plane or bridge to be repaired or modified where it stands or disassembled for recycling.

The composite expands the definition of material, says Hod Lipson, a Cornell University associate professor of mechanical and aerospace engineering who was not involved in the M.I.T. work. Typical materials repeat their basic components at an atomic and molecular scale. This material repeats at the macroscale, making the entire assembly a strong, flexible solid, he says. Structures made with the composite would not have joints that can fail catastrophically, and the bit-by-bit construction could make custom fabrication easier.

The basic building block is a carbon-fiber-reinforced polymer shaped like a flat X about two inches across, with a rectangular node at the center and small loops at the end of each arm. One piece is linked to another by connecting a loop to a node. Each node holds four loops, secured in place by a stiff carbon-fiber clip, forming a cubic lattice of octahedral cells—a structure with eight

An elastomer robot could help doctors perform angioplasty by delicately anchoring to vascular walls without damaging them.

plane surfaces called a cuboct. The M.I.T. laboratory has built and tested dozens of blocks that sport arm lengths from almost six inches down to tenths of an inch. Making the composite with different densities (determined by arm thickness) and different cell sizes (determined by arm length) affects the material's stiffness and weight, determining how well it resists bending or buckling.

How to best assemble the pieces remains a challenge. At this stage the researchers painstakingly link the pieces using tweezers. But M.I.T.'s Center for Bits and Atoms is devising a team of robots that could build objects out of the material or crawl over an existing structure to make repairs. Kenneth Cheung, a former postdoctoral M.I.T. researcher who helped to develop the composite and now works at the NASA Ames Research Center, says an assembly system "will work best with separate robots for individual tasks, such as inspection, installation or removal."

Other researchers are also tackling the rapid assembly problem. Lipson leads a team that has designed robots that can identify where they are and know where they need to go. Such robots could construct materials involving billions of building blocks, he says. Robots could also quickly construct temporary levees during a flood or fabricate satellites in space.

The composite will have to pass qualification and safety certification standards before airplanes or cars made of it roll off robotic assembly lines. Completely novel structures could be built, including planes with morphing wings and robots with flexible yet jointless arms, Cheung says. Yet the material will probably appear in other applications sooner; unmanned satellites or space probes could launch in a few years, he says.

—*Marissa Fessenden*

SOFT ROBOTS

Worms and octopuses inspire pliable machines that go where no metallic robots can

Rescue crews arrive on the scene of a collapsed mine and drill a borehole several hundred meters down to a small cavern. They put a cylindrical, camera-equipped robot made of metal into the hole that will descend and search for survivors. As the robot crawls downward, the ground shifts, collapsing the borehole to half its diameter, crushing the bot. Now what? If the robot had been made of deformable polymers, it could have simply lengthened and narrowed its shape, like a worm, and continued on its mission.

Such "soft" robots exist today only in the laboratory, but advances in materials science, control theory, energy storage and flexible electronics could change that. Pliable automatons could soon be available to perform demanding tasks in mines, factories, as well as inside the human body.

In building soft robots, engineers are copying the movements of octopuses, worms and other invertebrates. Why spend the time and money to reproduce a human hand using actuators, cables and motors, when a pneumatically powered polymer tentacle could do the job cheaper and more efficiently? In one such attempt, researchers at Cornell University fashioned a "universal gripper" from a small ball filled with air and coffee grounds. When the gripper came into contact with an object, it conformed to that object's shape. By vacuuming out the air inside the ball, researchers made the ball slowly stiffen, delicately grasping the object. Alternatively, a similar robot could be made out of soft polymers that expand, contract and bend in response to electric currents.

Conventional, vertebrate-inspired robots may be faster and stronger than their pliable counterparts, but soft robots powered by air pressure or electric currents could be more effective at manipulating a wider variety of items and more adaptable to moving in diverse settings. Their rubbery composition might also make them more likely to survive being toppled or trampled on a factory floor.

Researchers at Harvard University's Whitesides Research Group have made a variety of shape-shifting polymer robots, including a meter-long quadruped that looks like a pair of Ys joined at the stems. Air pumped into valves in the robot's layers of pneumatic channels causes the creature to inflate, bend and move various legs to inch along. Equipped with its own battery and air compressor, the robot has undulated and crawled across the lab floor, through snow and even across a hot grill. In 2011 the researchers built a much smaller, tethered version that squeezed through a space just a few centimeters high. "The range of opportunities is much larger if you can operate them untethered, and we've crossed that crucial line," says George M. Whitesides, a renowned Harvard chemist and materials scientist. The scientists are also improving the robot's speed with more efficient transfer of compressed air through internal channels, rather than having parts of the bot "bulge in unproductive ways," Whitesides notes.

Inspired by the progress, investors are in the process of licensing the technology and recently launched a start-up company, Soft Robotics, to devise biomedical devices. An elastomer robot could, for example, help doctors perform a biopsy or angioplasty by delicately grasping tissue or anchoring to vascular walls without damaging them.

Within the next decade commercial products may make their debut as wearable support devices—artificial muscles that provide physical assistance to people who have motor impairments or who work lifting heavy items, say, in warehouses, according to the inaugural issue of the journal *Soft Robotics*. The Defense Advanced Research Projects Agency is also interested in funding development of soft robots for reconnaissance missions and as prosthetics, as part of the agency's Maximum Mobility and Manipulation program.

The success of soft robotics

still depends on advances in a number of technologies, however. North Carolina State University researchers are tackling the materials angle by developing a water-based hydrogel that can be patterned, folded and used to manipulate objects. Hydrogels, which use water as their swelling agent, are elastic, translucent and potentially biocompatible. In one experiment, researchers injected copper ions into a V-shaped segment of hydrogel that caused the V to flex like a pair of tweezers. In another, a chemical reaction caused an X-shaped piece of hydrogel to fold in the shape of a four-pronged grabber.

The greatest advantage of soft robots may also be the easiest to overlook. A piece of polymer, some air tubes and a small power source are likely to cost a fraction of what it takes to make a moving, metallic robot. The savings could lead to pervasive use—if people are willing to accept robots that look more like cephalopods than the Jetsons' humanoid maid Rosie.

—Larry Greenemeier

METAMATERIALS

Novel substances that can deflect light could lead to superfast Internet and razor-thin smartphones

Tiny arrays of microscopic metal rings and rods bend, scatter or transmit electromagnetic radiation in ways not possible before.

Nikolay Zheludev's voice in the U.K. traverses the Atlantic Ocean on wires, fiber-optic cables and microwaves and reaches me in New York City. The delay and noise make a conversation difficult. Speaking from the University of Southampton, he is describing man-made structures called metamaterials and how they will make almost any conceivable device or application faster, cheaper and more efficient. Our transoceanic conversation is a case in point, he notes: over a metamaterial-augmented all-optical network, the static, the awkward pauses and the cross-talk at the ends of our sentences would be eliminated. "We are no longer limited by what nature gives us or what we can cook with chemistry," Zheludev says. "We can do better."

Metamaterials are made up of tiny arrays of microscopic elements such as metal rings or rods that can bend, scatter or transmit electromagnetic radiation in ways that no natural material can. The elements must be smaller than the wavelength of the radiation they are intended to manipulate. Picture a net so small it can deflect a wave of light the way the tall netting behind home plate on a baseball field deflects foul balls. Now imagine that by tweaking the size and composition of the gaps in the net, you can not only deflect light or allow it to pass through but also alter its trajectory, change its color or even make it disappear. Metamaterials manipulating light in these ways could form the basis for more reliable wireless Internet connectivity, denser data storage and all-around more capable electronics, not to mention a smartphone as thin as a credit card.

Yet many of these improvements will become reality only if and when metamaterials are made that work with visible light. At present, metamaterials work best for longer-wavelength radiation such as radio waves and microwaves, which require elements that are on the order of tens of millimeters. Such elements can be easily fabricated by several common manufacturing techniques.

In January a team led by David Smith of Duke University demonstrated a metamaterial-based microwave camera that requires minimal data storage and sensors, which could replace bulkier, costlier microwave imagers now used in some airport security booths. A company called Kymeta is also using Smith's work in a new, low-power, high-bandwidth reconfigurable antenna for airplanes, ships, trains and cars that could go on sale as soon as next year, bringing cheaper high-speed satellite Internet to passengers in those vehicles. And researchers are devising "invisibility cloaks"—metamaterial shells that can bend radio waves or microwaves around objects to conceal them from radar.

Making metamaterials for shorter wavelengths such as visible light is more difficult because it entails making elements much smaller than a micron, approaching the sizes of components on modern computing chips. Furthermore, many applications require a configuration of elements that can change to manipulate light in different ways, on the fly.

Zheludev calls these dynamic arrangements "metadevices," and with collaborators he has already created a few in his laboratory. In March his team published a "proof of concept" for an optical metadevice made of nanoscale elements etched in gold films, which are then connected to microscopic strings. Each element's position can be electronically controlled through the strings, thereby allowing the device to be reconfigured in real time to alter how it transmits or reflects visible light. Zheludev says the technology could make an ideal switch for ultrafast optical communications and computers.

The best way to master metamaterials for visible and near-infrared light, however, may be to first perfect flat, two-dimensional "metasurfaces," according to researchers such as Federico Capasso of Harvard University. Only then could scientists consider making more complicated, three-dimensional assemblies for applications such as true-color holographic displays or Harry Potter–style invisibility cloaks that make people and objects we can see disappear. His group's most notable success so far is arguably its "flat lens," which focuses a beam of light into a pinpoint and could lead to wafer-thin smartphones and digital cameras; lenses and batteries are the limiting factors in further flattening these products.

Although much work remains before metamaterials become common in practical products, "I do think this stuff has the right flavor," Capasso says. "Influential people are taking notice. They tell me, 'Federico, what you are cooking smells good!' " *—Lee Billings*

MICROBIOME

Microbes in our gut could be manipulated to fight illnesses and infections

We rely on trillions of bacteria, fungi, archaea and viruses in our mouth, on our skin and in our gut to get through the day and to stay healthy. Scientists had no way to study most of these microbes, which do not seem to want to grow in laboratory cultures. Rapidly improving, low-cost genetic-sequencing technologies are finally making it possible, however. By working with our microbes instead of against them, scientists are coming up with intriguing approaches to tackling persistent diseases and improving our overall health.

A few years ago scientists could only dream of studying large communities of microorganisms, but now such experiments are manageable and affordable, says David Relman, a professor at the Stanford University School of Medicine. This new field of metagenomics is giving scientists profiles of what microbe populations look like in the gut of people who are healthy—and in the gut of people who have various conditions and diseases. Armed with these data, scientists are poised to explore the possibility of manipulating the balance of our microbiota as treatments for obesity, inflammatory bowel disease and many other common and uncommon ailments.

For example, researchers have profiled the populations of organisms in people with ulcerative colitis, which forms ulcers in the colon and is linked to changes in the gut's flora. Building on the results, this summer pharmaceutical giant Johnson & Johnson (J&J) announced a $6.5-million deal with Second Genome, a microbiome start-up, to develop treatments. Current approaches, which center on anti-inflammatory drugs, immunosuppressant medications and surgery, are often unsuccessful. A therapy that directly alters the microbiome would potentially create fewer side effects and fend off other infections down the road.

The J&J deal is a watershed, says Rita Colwell, who holds health appointments at the University of Maryland and Johns Hopkins University. "There's a moment for any new biotechnology that's critically important: when it moves from being an area of academic interest to one that companies are founded on," she notes. "And then there is the next step: when the big pharma money arrives."

The new treatments would be a big improvement over current attempts to improve the microbiome, which consist mainly of fecal transplants and probiotics—live bacterial cultures in supplements or foods such as yogurt. Fecal transplants have alleviated *Clostridium difficile,* a tough, often drug-resistant, toxin-producing bacterial infection, but the practice can require multiple transplants, and not all patients are cured. Probiotics have generated only weak evidence for positively changing the gut. Both treatments amount to throwing a bunch of organisms at the gut and seeing what sticks.

Metagenomics is more specific, providing precise genetic profiles of what organisms are in the gut and offering the possibility of deducing how they might be interacting—with one another and with us.

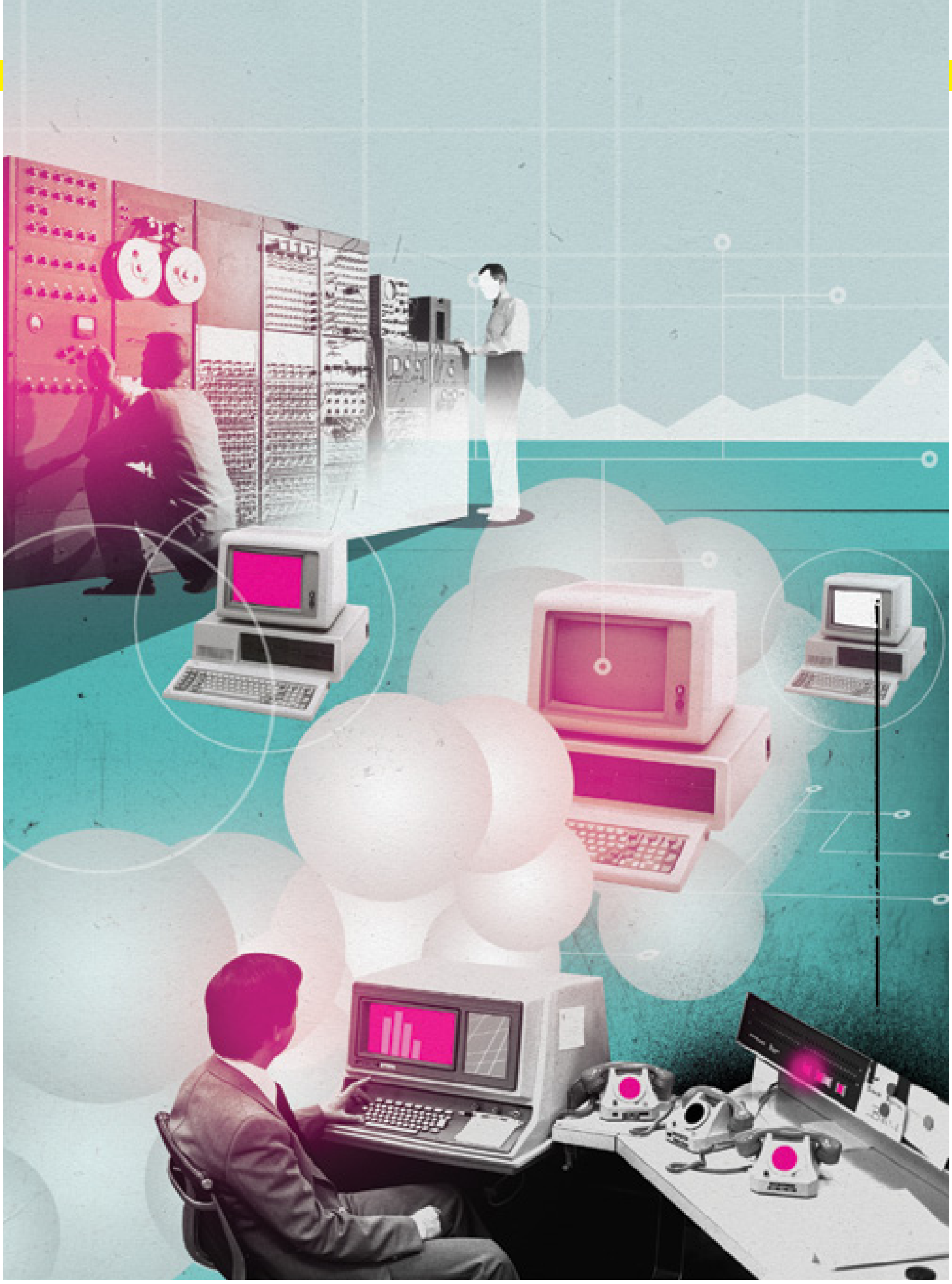
One of the biggest challenges of metagenomics is how to handle the onslaught of data. Now that scientists can rapidly sequence entire swaths of microbial communities, they need to figure out what the information means for our health. Biologists are teaming up with mathematicians to develop new methods of analyzing the DNA fragments they collect from our body. Physicians will then need to understand what changes occur in an individual's microbiome—and why—to protect or improve health.

For example, many people routinely carry *Escherichia coli* bacteria without getting sick. Relman likens the hope of curating better gut microbiota to maintaining a healthy ecosystem, one that will keep nasty creatures such as the intestinal equivalent of invasive weeds at bay.

Indeed, metagenomics is prompting us to think about caring for our microbial communities as we would cultivate a piece of land. This approach would be a sea change from the one-shot treatments that often have many negative effects. Broad-spectrum antibiotics, for example, wipe out our good bacteria along with the bad—opening up doors for pernicious invaders. Proton-pump inhibitors, sold over the counter to neutralize stomach acid, change the pH in the stomach, which could stress collections of beneficial microbes.

Metagenomic treatments instead might involve a series of interventions calculated to disturb the microbiome in a certain way, by introducing specific organisms that are prevalent in a healthy gut, followed by dietary and lifestyle changes.

—*Katherine Harmon Courage*



CLOUD COMPUTING

A new type of security chip guards against big data snooping

BY CONNECTING laptops and smartphones to enormous, remote computing banks, cloud computing gives us access to more processing power than could ever fit in any one of those devices, along with access to all our data and documents from anywhere in the world. The Achilles' heel is security: data that live in the cloud are vulnerable to hackers.

Solutions to two of the biggest vulnerabilities may be at hand, however. Researchers at the Massachusetts Institute of Technology say they have devised a way to protect servers against memory-access pattern-analysis hacks and timing attacks. The solution, in brief, is to install a chip they call Ascend that sends out a smokescreen of false information every time a server requests data from a remote source.

Even when data are encrypted, the way in which a computer stores and accesses that data—its memory-access patterns—can reveal unsettling private details. Suppose a person goes to Google Maps and asks it to find a driving route from Boston to Toronto. "By looking at the access pattern, an eavesdropper learns where you are, your route and your final destination," says M.I.T. computer

The security chip sends requests to the computer's memory at regular intervals, even when it requires no new information. That way attackers cannot tell how long the computer is spending on any specific data.

scientist Christopher Fletcher.

Cloud servers can also reveal secrets based on the amount of time they take to do certain computations. Imagine that a cloud server is asked to compare a surveillance photograph of a criminal suspect with random images on the Web. "The surveillance photo itself would be encrypted and thus secure from prying eyes, but spyware in the cloud could still deduce what public photos it was being compared with," Fletcher says. The time the comparisons take could reveal something about the image of the criminal suspect. "Photos of obviously different people could be easy to rule out, but photos of very similar people might take longer to distinguish," he explains.

These two types of attacks are especially dangerous because they are covert. The person on Google Maps and the people analyzing the criminal photograph get the same results that would have arisen if no one had been hacking the transactions. "They don't know that security has been compromised," Fletcher says.

To protect against memory-access attacks, any time a server requests data from an address, it can request information from every address it knows. It could then throw away all the data except for the information it was seeking in the first place. The problem with this approach is pretty easy to see: it is far too time-consuming to be practical.

Ascend uses a more economical scheme. To start with, it assigns a piece of data it might look up to a random node in a network of data. When the processor requests data from a specific node in the network—for instance, an address in Toronto—it must send requests to all the other nodes in the network that are connected to it: nodes that contain addresses everywhere from Tampa to Timbuktu. An eavesdropper cannot tell which node the computer is looking for on any given path in the network. Ascend keeps this smokescreen robust by moving nodes around, too.

Ascend's method for protecting against timing attacks is simpler: it sends requests to a computer's memory at regular intervals, "even when the processor is busy and requires no new data," Fletcher says. That way attackers cannot tell how long a computer is spending on any specific piece of data.

This security comes at a cost—Ascend would work at one-sixth the speed of conventional server chips that are running ordinary programs popular among users. "That's the difference between Google getting a response back to you at the speed it does now versus getting a response back several seconds later," Fletcher says. The bigger drawback, at least for now, is that the chip exists only in theory. Fletcher and his colleagues detailed their chip architecture in June at the International Symposium on Computer Architecture in Tel Aviv, and they are building an Ascend chip now. They expect to finish the prototype in early 2015. *—Charles Q. Choi*

DRUGS

A toolbox-size lab flags knockoff pills and potions

UP TO 30 PERCENT of the medications in the developing world are poor in quality because either they are improperly manufactured, degraded because of age or poor storage, or produced as counterfeits in rogue factories. The bad medicines can cause severe side effects and death. Identifying them is challenging, however. Many countries lack regulations or routine inspections. Testing equipment can be scarce, cumbersome and costly and can require extensive training—and provide only partial information about a drug's ingredients.

A new device from Boston University, called PharmaCheck, may offer a portable, inexpensive and informative solution. The toolbox-size unit reveals the concentration of active ingredients, as well as how fast they are released. This "dissolution rate" sets PharmaCheck apart from other technologies, says Muhammad Zaman, a biomedical engineer who leads the work; active ingredients that break down too quickly can cause a life-threatening overdose.

To use PharmaCheck, an individual dissolves a pill in a few deciliters of water, then adds a second solution, included in the kit, called a fluorescent probe, which is tailored to bind to the active ingredient in a particular drug or class of drugs. The probe and dissolved drug interact in tiny channels etched into a silicon-polymer testing chip. The probe fluoresces, emitting light that is read by a sensor. Software translates the reading into an estimate of the ingredient's concentration, according to calculations made by Zaman's laboratory. Monitoring the signal over time indicates the ingredient's dissolution. Within minutes a doctor, regulatory official or health worker can have a definitive answer as to whether or not a pill is safe.

This winter Zaman will test prototypes in Ghana and Indonesia, with help from Promoting the Quality of Medicines, an international aid program. So far the team has crafted three probes for antimalarial and antibiotic drugs—among the most common substandard medications in circulation. They will add probes for uterotonic drugs (which induce labor) and antituberculosis and anti-HIV medications. Researchers must design a probe for each active ingredient, and PharmaCheck can test only one at a time. It cannot directly detect unwanted ingredients, such as cheap filler materials; however, because impurities generally alter the way in which an active ingredient breaks down, the portable lab could flag their presence.

PharmaCheck is one example of the great progress made in microfluidics: technologies that manipulate liquids within channels much less than a millimeter wide. "This could not have happened 10 years ago," Zaman says. In the future, so-called labs-on-a-chip could test dietary supplements or veterinary medicines or rapidly screen blood and saliva samples.

Researchers elsewhere are developing other approaches to identifying substandard medicines. Chemists at St. Mary's College and the University of Notre Dame, for example, have created a paper card that users can dampen and rub a crushed pill across, which generates a colorful array to confirm a pill's contents.

If these kinds of tests were available to small pharmaceutical companies, pharmacies, hospitals, health workers and government regulators, quality could be assessed at every stage of the drug pipeline. That rigor could also help stem the influx of poorly made generic drugs into the developed world, as well as counterfeits sold online for blockbusters such as Viagra.

—Daisy Yuhas

ELECTRONIC DISPLAYS

Flexible, stretchable screens could put a rolled-up tablet in your pocket

RESEARCHERS HAVE BEEN trying for years to develop flexible electronic displays, a breakthrough that would bring us tablet computers that fold and roll up and clothing with stretchable video screens embedded in the fabric. The biggest problem has always been finding a malleable, ultrathin base layer, or substrate, on which to build the display. Polymer LEDs (PLEDs)—a form of the organic light-emitting-diode displays now going into extravagantly expensive, vanishingly thin televisions—are mere microns thick and pliable. The problem is that they have always needed to be manufactured on a plastic or glass substrate, which is usually somewhere between 1,000 and 10,000 times thicker than the PLED itself and not particularly flexible.

By changing the method of manufacture, however, it is possible to get rid of those thick, inflexible substrates. Using a "peel-and-stick" technique, an international team of scientists made PLEDs just two microns thick—several times thinner than plastic kitchen wrap.

First, the researchers apply a 1.4-micron-thick sheet of Mylar film, which will serve as the substrate for the PLED, to a rigid glass support. The Mylar sheet is similar to the screen protector that today comes on most new, out-of-the-box smartphones and tablet computers, says researcher Matthew White, a materials scientist at Johannes Kepler University in Linz, Austria. "We just realized that we could apply the [peel-and-stick] method to device fabrication and push the limits of how thin you can make the substrate."

Once the Mylar film is in place, White and his colleagues deposit the PLED on top. The PLED has three layers: a 100-nanometer metal electrode, a 200-nanometer transparent electrode, and a light-emitting layer 225 to 330 nanometers thick sandwiched in between. When those elements are on the Mylar, the researchers peel the entire thing off the glass. The resulting display is as light, flexible and crushable as one would expect kitchen wrap to be.

Depositing the PLED elements on a thin, rubbery base layer makes a screen that is stretchable. The stretchiness is, theoretically, only limited by the stretchiness of the base layer.

This past summer the scientists fabricated two pliable, eight-pixel PLED displays, one that glows red and one that glows orange. Each pixel measures three by six millimeters, much larger than the tiny pixels in today's high-resolution screens. The PLEDs are nearly display-quality in brightness, however, and the researchers are confident they can shrink the pixel size readily.

The light-emitting-diode displays are as thin, light and crushable as one would expect kitchen wrap to be; one glows red, and one glows orange.

Plenty of hurdles remain before these displays are ready for the market. The biggest: the metal electrodes are unstable in air; in about an hour the pixels gradually go dark. Different materials will be needed before the technology is ready for prime time. The displays are not particularly energy-efficient, either, although White says his team sees a clear path toward making them as efficient as conventional lighting.

—Charles Q. Choi

DISEASE

Small tubes of antiseptic could prevent 500,000 infant deaths a year

WHEN A BABY IS BORN in rural Nepal, its severed umbilical cord is commonly tied with a thread of raw cotton. In many cultures, the cord stump is also rubbed with ash, oil, butter, spices, mud or even dung. Throughout the developing world, birth attendants with unwashed hands use dirty knives, scissors, razor blades or broken glass to cut the cord. Freshly cut umbilical cords are attractive breeding grounds for bacteria, and such practices are a major reason why the biggest threat to newborn babies in the developing world is infection.

Medical orthodoxy has long held that umbilical cord stumps should be left untreated until they fall off, and in sterile environments such as Western hospitals, this method works well. Yet for the developing world, doctors are beginning to rethink that recommendation.

If cord stumps were instead treated with chlorhexidine, a cheap and widely available antiseptic, it could save 500,000 infant lives per year.

Chlorhexidine, which has been used for years in surgical procedures, is effective, safe, simple to use and requires no refrigeration. It is more powerful than soap and water but less harsh than other antiseptics. It is affordable, too: a single-use tube costs about 23 cents.

In 2002 public health researcher Luke Mullany of Johns Hopkins University and his colleagues began a field trial in Nepal to find out whether using the antiseptic would make a noticeable difference in neonatal mortality. The results were unambiguous: when dabbed onto the umbilical cord stump within the first days of life, chlorhexidine reduced the risk of death by 24 percent. Researchers later estimated that if the antiseptic were used widely in poor countries, both for home births and in health facilities where neonatal mortality is high, it could prevent roughly one in six newborn deaths. "It has the opportunity to be a game changer," says Carl Bose, a neonatologist at the University of North Carolina at Chapel Hill who was not involved with the field trials.

In Nepal, where most babies are born at home, health care workers in 41 of the country's 75 districts are now distributing free, single-use gel tubes to women in their final months of pregnancy. Western organizations have paid for the effort so far, but the Nepalese government is scheduled to begin funding the program this year and plans to distribute chlorhexidine nationwide by 2015. Similar pilot programs are in the works in Nigeria, Zanzibar and Zambia.

At press time, the World Health Organization is expected to formally recommend that the antiseptic be used during the first week of life in home-birth settings where risk of death is high. Advocates say that this is a good step but point out that the WHO still promotes "dry cord care" (leaving the cord untreated) in low-resource hospitals and clinics. Instead, they say, it should promote chlorhexidine in those settings, too. Antiseptics can increase the time it takes for the cord stump to fall off, but studies suggest the delay poses little risk. "If the WHO doesn't recommend something, it often doesn't happen," Bose says. "It could be an opportunity lost."

—Dina Fine Maron

MORE TO EXPLORE

Reversibly Assembled Cellular Composite Materials. Kenneth C. Cheung and Neil Gershenfeld in *Science,* Vol. 341, pages 1219–1221; September 13, 2013.

Metagenomic Profiling of Microbial Composition and Antibiotic Resistance Determinants in Puget Sound. Jesse A. Port et al. in *PLOS ONE,* Vol. 7, No. 10, Article No. e48000; October 29, 2012.

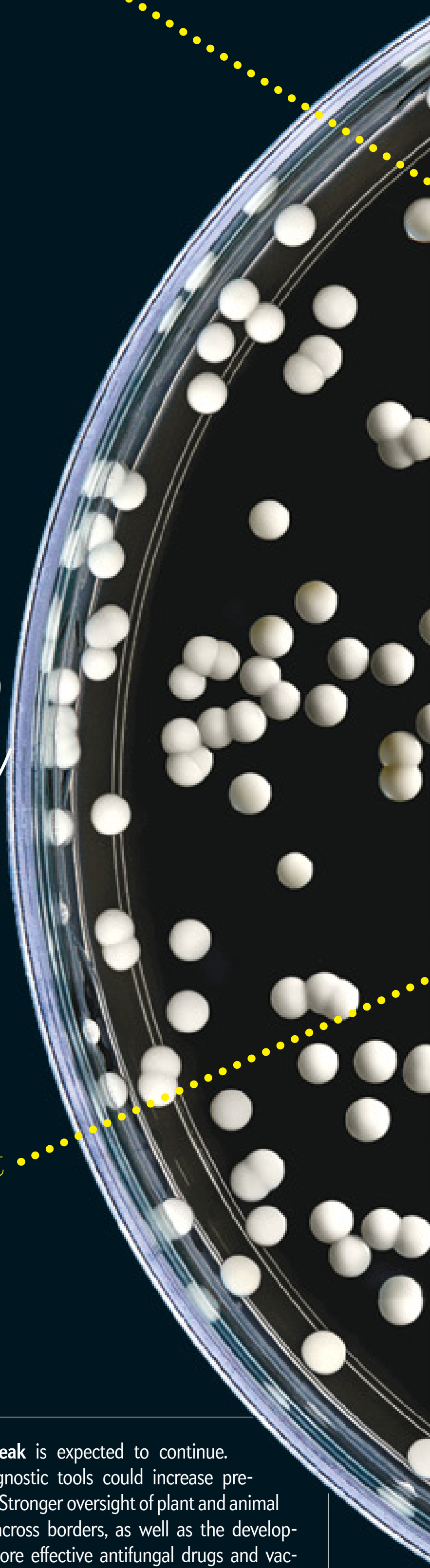
Soft Robotics, a new journal: **www.liebertpub.com/SoRo**

SCIENTIFIC AMERICAN ONLINE
For video explaining how metamaterials can be used to create invisibility cloaks, see **ScientificAmerican.com/dec2013/world-changing-ideas**

A strange fungal disease in Canada and the U.S.

INFECTIOUS DISEASE

Fungi on the March



heralds a new threat to human health

By Jennifer Frazer

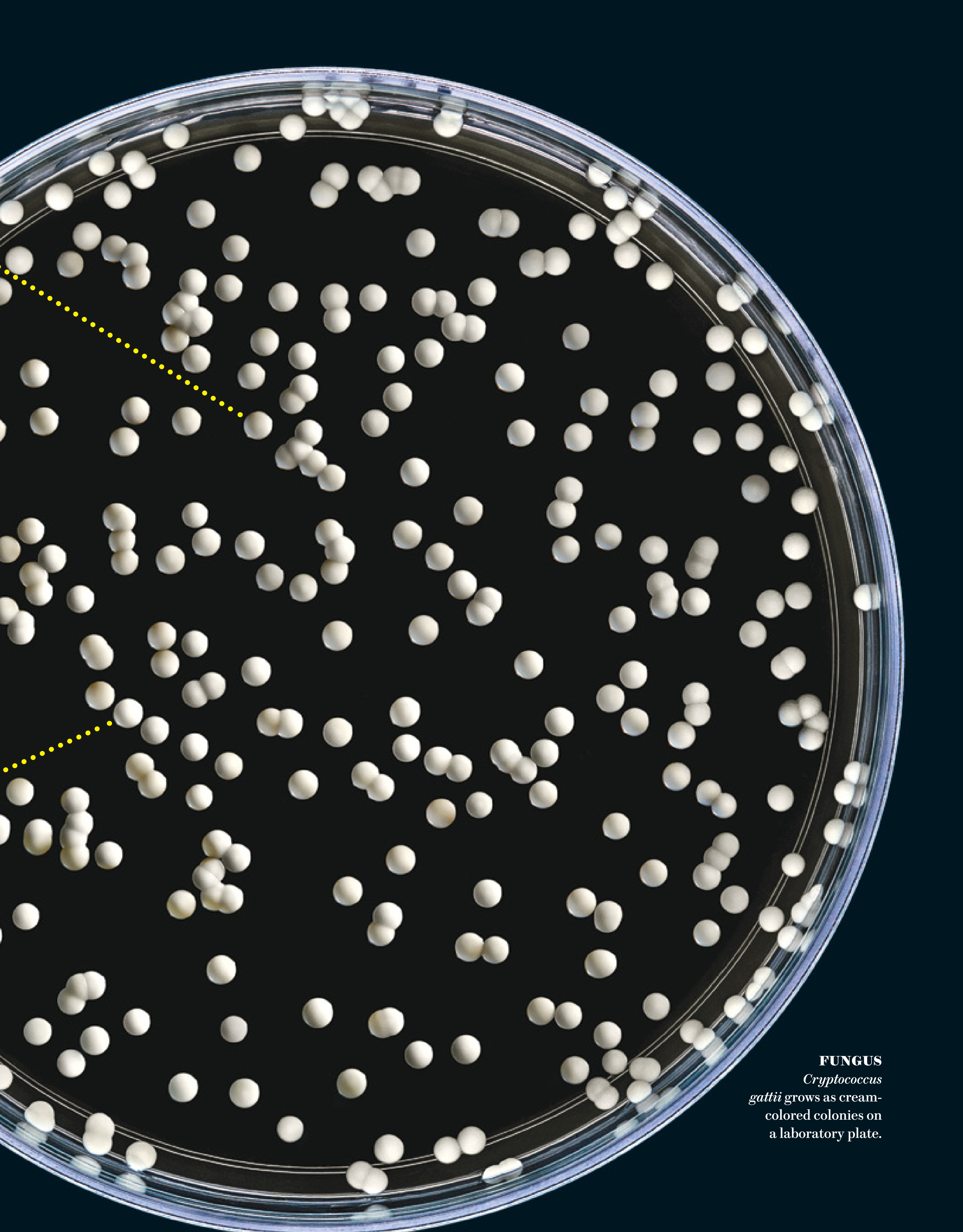
IN BRIEF

An airborne yeast that was found to have sickened apparently healthy people on Vancouver Island in British Columbia in 2001 became the first known human fungal pathogen to suddenly become more virulent in a place where the organism was previously unknown.

Determining where the yeast came from proved difficult. Eventually researchers realized that it was hiding out in surprising locations and that its emergence as a cause of serious illness in British Columbia may well have been prompted by climate change and land development.

The outbreak is expected to continue. Better diagnostic tools could increase preparedness. Stronger oversight of plant and animal transport across borders, as well as the development of more effective antifungal drugs and vaccines, also could help.

Photograph by Zachary Zavislak



FUNGUS
Cryptococcus gattii grows as cream-colored colonies on a laboratory plate.

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IN 2001 DEAD PORPOISES WITH YEAST-PACKED LUNGS WASHED UP ON THE SOUTHEASTERN shore of Vancouver Island in British Columbia. The bloated organs were several times normal weight, with barely any room for air. The island's veterinarians had never seen anything like it. Cats and dogs there were having trouble breathing, too. In cats, the disease could cause a particularly gruesome symptom: weeping holes, produced when a yeast infection ate its way through the skull. At the same time, a few people on the island, located off Canada's Pacific Coast, also began falling ill with an unknown respiratory malady. They coughed constantly, their energy sapped, their sleep stolen. Chest x-rays revealed ominous lung or brain nodules. Biopsied tissue, however, proved the culprit to be not cancer but yeast.

Despite their varying symptoms, the pets, porpoises and humans all shared a single tormenter: *Cryptococcus gattii*. This fungus had never been seen on the island before, nor was it known to survive outside the tropics and subtropics. Now it was present in the environment, although no one knew where it had come from or how long it had been there. Most worryingly, no one knew how many would be sickened or how far the upstart yeast might travel.

There was good reason for concern.

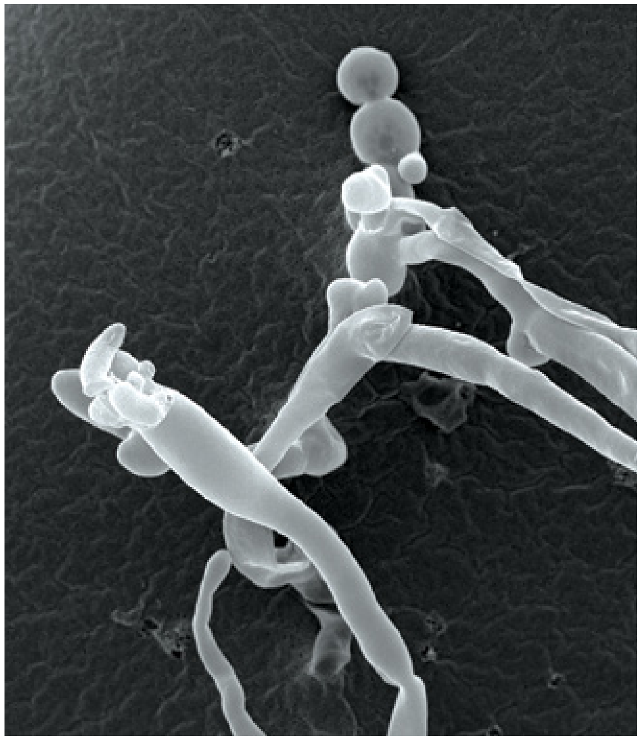
Fungi have long plagued plants—famously felling the towering elm and chestnut trees of the eastern U.S. and beyond. More recently, fungal epidemics have become alarmingly common among animals. From ponds in South America where frogs' fungus-clogged skin stops their heart to caves in the eastern U.S. where moldy, shivering bats drop pitifully from the ceiling, pathogenic fungi are running amok. Historically the fungi that infect humans have been known more for inspiring laughably bad commercials about trifling but irritating skin infections than for making people desperately ill. Our formidable immune system and torrid body temperature, too high for most fungi to tolerate, ensured that people in good health generally shook off serious attacks.

There were a few exceptions: in the U.S., inhaled diseases such as valley fever in the Southwest and histoplasmosis in the Midwest and Southeast have long quietly stalked healthy people. For reasons not completely understood, valley fever exploded eightfold within its usual range between 1999 and 2011. In recent decades fungal infections have also unsurprisingly surged as the immune systems of millions of people became impaired by infection with HIV or by immunosuppressive drugs given to protect transplanted organs or to treat disease. When defenses are down, pathogens will thrive. Overall, however, fungal attacks affecting many healthy people at once have been rare and largely caused by fungi within their usual ranges as they encountered favorable environmental conditions.

C. gattii is different. Until it emerged on Vancouver Island, it had occasionally sickened healthy people elsewhere but had never before caused an outbreak—a burst of unexpected infections. Its appearance in Canada seemingly also marked a jump into new territory with a much cooler climate, where the microorganism had inexplicably become more harmful. Between the outbreak's start and the end of 2012, 337 British Columbians were reported infected, of which two thirds were Vancouver Island residents, says Eleni Galanis, an epidemiologist at the

British Columbia Center for Disease Control. And by 2005 *C. gattii* had started making people sick farther south, in the U.S. Pacific Northwest. Since then, at least 100 people in that area have been infected, and 25 to 30 percent of them have died. "It's a fairly high mortality rate for an environmentally acquired fungus," says Joseph Heitman, director of the Center for Microbial Pathogenesis at Duke University. For the most part, although these are not AIDS patients, about half had weakened immune systems from prescribed drugs or illness, and many of the rest had common ailments that can weaken immune systems to a lesser extent, such as diabetes, or lung, kidney or heart disease. But 20 percent or more were healthy prior to infection. "Many of these patients were completely healthy, spending a lot of time outdoors, and suddenly they were very ill," Heitman adds.

Today the *C. gattii* outbreak is giving every indication that it will continue to move south. Immunologist Arturo Casadevall of the Albert Einstein College of Medicine thinks the yeast—fungi growing as single cells instead of long filaments—will ultimately reach Florida. Indeed, the events in British Columbia and the U.S. Pacific Northwest constitute a landmark in the history of human disease: the first known outbreak of a disease caused by a fungus that had suddenly and unexpectedly evolved markedly increased virulence. And another first—it did so in a place where the organism was previously unknown. The *C. gattii* story thus raises a disturbing prospect: healthy humans can no longer assume they are immune to life-threatening outbreaks of newly virulent fungi. Indeed, as global temperatures rise, we may be inviting more.



REPRODUCTION: A few sausage-shaped *C. gattii* spores cluster around the club-shaped structure that produced them (*left*). The spores grow in long chains; here the chains have been disrupted.

COURTESY OF DEBORAH J. SPRINGER AND JOSEPH HEITMAN *Department of Molecular Genetics and Microbiology, Duke University Medical Center*

EVERYWHERE AND UNSTOPPABLE

THESE INSIGHTS WERE STILL FAR IN THE FUTURE on Vancouver Island in June 2001, where public health officials were about to be blindsided. For disease investigator Murray Fyfe, then at the British Columbia Center for Disease Control, the first sign that something was amiss was a call from the provincial veterinarian informing him of an unusual increase in *Cryptococcus* infections among dogs and cats on the island. Local physicians confirmed a similar rise in human cases, and tests indicated that the culprit was not the usual *Cryptococcus neoformans* but a different fungal species—*C. gattii*. The team raided the center's culture collections to see if *C. gattii* had been infecting people on Vancouver Island all along and had simply been misidentified as *C. neoformans*. That turned out to be the case for some infections starting in 1999 but not in any years previous to that.

Fyfe, now a medical health officer at the Vancouver Island Health Authority, took several approaches to pinpointing where the fungus was hiding. In one line of attack, he assembled a team of investigators to look for new cases on the island and throughout British Columbia. The team interviewed patients and owners of infected pets, detailing symptoms and looking for commonalities and risk factors, such as previous illnesses or travel, and even investigating whether victims had eucalyptus trees in their yards. The fungus had been found living on such trees in Australia, where people had long been sporadically infected with *C. gattii*. They plotted cases on a map. They compared patients with individuals who did not get sick to see if any differences or trends emerged, a technique called a case-control study.

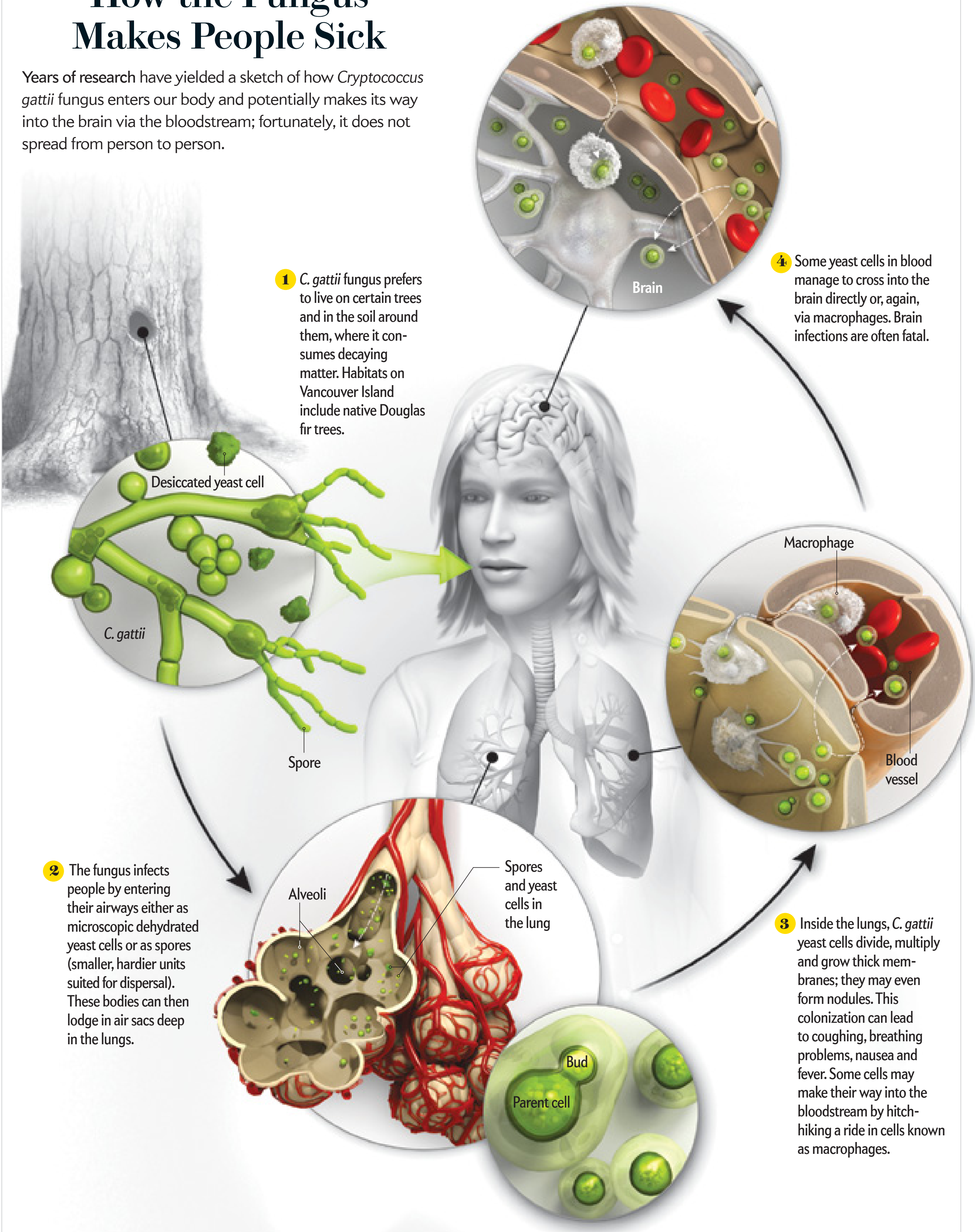
To track down *C. gattii* in the wild, Fyfe turned to Karen Bartlett of the University of British Columbia, an expert in the behavior of biological aerosols, such as fungal spores or other particles that can make their way into organisms' airways. Because *C. gattii* had been found on eucalyptus trees in Australia, she started by sampling the few specimens that grew on Vancouver Island. But Bartlett's swabs of these and other trees and soil revealed nothing.

The case-control study yielded no pay dirt, either. No environmental factor—say, gardening, cutting down trees or laying down bark mulch—seemed to put island residents at increased risk. The cases were scattered up and down the eastern side of the island with no clear epicenter. What is more, the victims had not all traveled recently to Australia or any other exotic locale, whence they might have carried the fungus.

The researchers were stymied. Their frustration dragged on for six months. Their break came when a handful of infected patients surfaced who did not live on Vancouver Island but who had traveled there. A few had been to the island's Rathtrevor Beach Provincial Park. A sampling team was dispatched. At last, one of the samples—from a Douglas fir tree, a common species in the vicinity—tested positive for *C. gattii* in early 2002. No one had expected the presumed exotic fungus to be hiding out in native trees. Ultimately Bartlett's team would isolate 57 *C. gattii* samples from 24 trees in the park belonging to several native species. By the end of that summer she had found the fungus in soil and air and on trees in Victoria, on the southern tip of Vancouver Island, up the eastern coast to Campbell River, and west to the central island. It was the same area

How the Fungus Makes People Sick

Years of research have yielded a sketch of how *Cryptococcus gattii* fungus enters our body and potentially makes its way into the brain via the bloodstream; fortunately, it does not spread from person to person.



1 *C. gattii* fungus prefers to live on certain trees and in the soil around them, where it consumes decaying matter. Habitats on Vancouver Island include native Douglas fir trees.

2 The fungus infects people by entering their airways either as microscopic dehydrated yeast cells or as spores (smaller, hardier units suited for dispersal). These bodies can then lodge in air sacs deep in the lungs.

3 Inside the lungs, *C. gattii* yeast cells divide, multiply and grow thick membranes; they may even form nodules. This colonization can lead to coughing, breathing problems, nausea and fever. Some cells may make their way into the bloodstream by hitchhiking a ride in cells known as macrophages.

4 Some yeast cells in blood manage to cross into the brain directly or, again, via macrophages. Brain infections are often fatal.

Illustration by Emily Cooper

in which most of the population of Vancouver Island lived. Probably everyone would be or had already been exposed, and there was nothing that could be done about it.

More worrying news followed. Data collected between 2002 and 2006 eventually showed that the infection rate on Vancouver Island was 27.9 cases per million in the population—three times higher than the rate among humans in tropical northern Australia. North Americans could well have a more virulent pathogen on their hands, although a lack of previous exposure to the fungus might also explain the pattern; if the fungus was a new arrival, few if any people in the area would have encountered it and built up an immunity to it earlier in life. Tests performed on the organism were also unsettling. It could survive in freshwater. It could survive in saltwater. It could survive in air. It could survive for years in mud on shoes. Parallel work showed that *C. gattii* was on the move. Cases began appearing on the mainland of British Columbia in 2004 among people who had never visited Vancouver Island. Modeling showed that the organism preferred warm winters, low elevations and dry conditions. Points south seemed to offer fertile ground. In February 2006 an older man with leukemia taking immunosuppressive steroids who lived in the U.S. San Juan Islands off the coast of Washington State came to his doctor with a cough. His chest x-ray revealed a nodule; it was *C. gattii*. Genetic analysis by Heitman in collaboration with Kieren Marr, a physician-scientist then at the Fred Hutchinson Cancer Center in Seattle, revealed that the fungus was indistinguishable from a Vancouver Island strain. Although the man lived within a few kilometers of the Canadian maritime border, he had never traveled to Canada. The fungus had come to him.

Tests performed on the organism were unsettling. It could survive in freshwater. It could survive in saltwater. It could survive in air. It could survive for years in mud on shoes.

WHY NOW?

ALTHOUGH RESEARCHERS realized by the mid-2000s that little could be done to stop the spread of the *C. gattii* outbreak in North America, they still wondered how long the fungus had been in British Columbia and the U.S. Northwest, where it came from and what caused it to suddenly start making so many people sick. They found clues by analyzing its DNA.

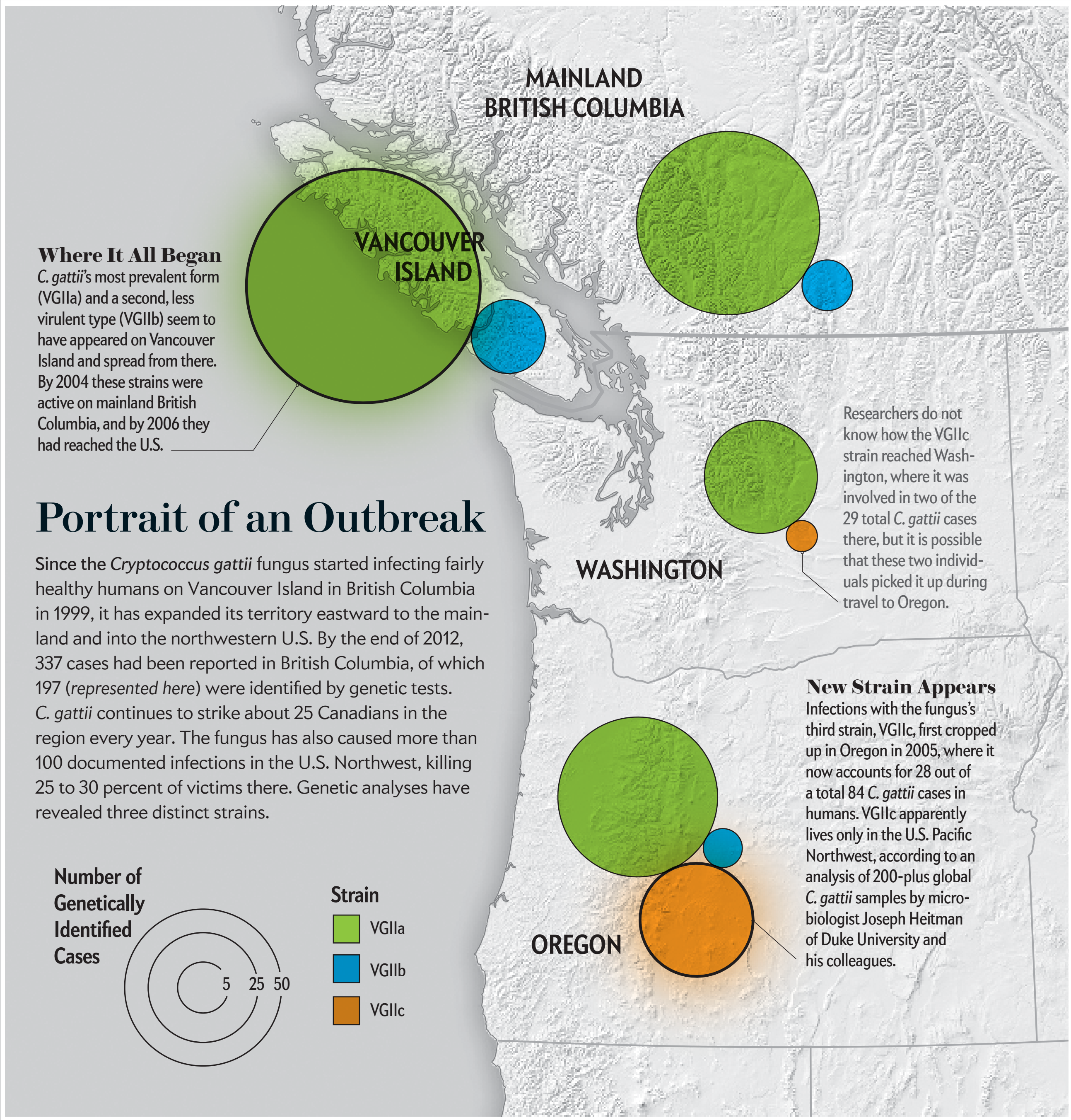
The genetic work revealed that the fungus may have been in the vicinity of Vancouver Island for up to several decades before 1999, Heitman says. The sequence of DNA "letters" in the major type of *C. gattii* ultimately found on the island—called VGIIa and responsible for 90 percent of infections on Vancouver Island—is indistinguishable in more than 30 sampled sections of DNA from the corresponding sections of DNA found in a sample of sputum collected from a man in Seattle around 1971. His travel history is unknown, and it is possible he had visited Vancouver Island. Regardless, this evidence seems to indicate that VGIIa has been present in the Pacific Northwest for at least 40 years. In the years since the outbreak, scientists have discovered that varieties of *C. gattii* that are less virulent and do not cause outbreaks also occur in North America, so it is possible VGIIa evolved there. But *C. gattii* could also have been introduced from Africa, Australia or South America, where the species is endemic as well.

A second *C. gattii* type—VGIIb, which researchers later realized had begun causing illness simultaneously with VGIIa on Vancouver Island in 1999 and occurred in just 10 percent of the patients sickened in the initial outbreak—is indistinguishable from a strain currently circulating in Australia. That continent may be the b type's source. Oregon now harbors these two forms as well as a third: VGIIc. This last strain appeared suddenly in Oregon in 2005, although whether it arose there or elsewhere is unknown.

Worryingly, in mice at Heitman's lab at Duke, samples of VGIIa and c proved to be the two most virulent forms of *Cryptococcus* the group had ever tested. This finding and others suggest to Heitman that some kind of sexual reproduction among undetermined types of *C. gattii* generated the VGIIa and c strains and bestowed their increased virulence. Sexual reproduction promotes diversity among offspring by mixing the DNA of parents in new combinations. In fungi, the act of sex itself also generates mutations that can produce new traits. The presumed bouts of fungal sex could have taken place either in North America or in *C. gattii*'s known haunts in Australia, South America or Africa, where researchers simply have not yet found the parent fungi.

Also unknown is whether the outbreak strains came from abroad and, if so, whether they made their way to North America separately or together. Scientists can conceive of many scenarios for their arrival: plant, soil or animal imports or long-distance migrations by wind or ocean currents have all been proposed. The fungus could have hitched a ride in the ballast water of a ship. Infected porpoises could have crossed the Pacific on their own and released the organism to the soil or to scavengers when they died and their corpses washed ashore. Mud on vehicles or footwear could have carried the fungi from one place to another. The trip or trips that brought the fungi to North America may have taken place 10,000 years ago—or 43 years ago.

There is at least one clue, however, to how long these fungi have been in the Pacific Northwest. Fungi that have been in one place for a long time tend to diversify genetically. The three types of *C. gattii* causing outbreaks in the region are clonal—all the fungi of a given type, be it a, b or c, are genetically quite similar. "If it's been there 100,000 years, then you'd expect to find a lot more diversity in the population, and you



SOURCES: "*CRYPTOCOCCUS GATTII* IN THE UNITED STATES: GENOTYPIC DIVERSITY OF HUMAN AND VETERINARY ISOLATES," BY SHAWN R. LOCKHART ET AL., IN *PLOS ONE*, VOL. 8, NO. 9; SEPTEMBER 3, 2013 (*Oregon and Washington*); BC CENTER FOR DISEASE CONTROL (*Vancouver Island and British Columbia mainland*)

Map by XNR Productions; Graphic by Jen Christiansen

don't see that," Heitman says. "From my perspective, that may be the strongest case that maybe [these fungi] really [were] brought there 50 years ago or 70 years ago or 100 years ago" and not thousands of years earlier.

As for why *C. gattii* caused no outbreaks until recently despite being in the vicinity for at least 40 years, one possibility is climate change. The average temperature on Vancouver Island increased by a degree or two Celsius during the past 40 years, Bartlett says. That "doesn't sound like much, but it can be a huge difference to microorganisms," she adds. The years 1991, 1993, 1994, 1996 and 1998 all had above-average summer temperatures for Vancouver Island. Warmer temperatures may have allowed a subtropical organism that was previously teetering on the edge of survivability there to thrive. As the planet warms, Casadevall says, existing pathogenic fungi that like heat could extend their ranges into formerly inhospitable habitats. Indeed, plant-pathogenic fungi have already been found to be moving toward the poles in response to climate change at the particularly brisk clip of about seven and a half kilometers a year since 1960. Meanwhile hotter climates may encourage other fungi to evolve tolerance to warmer temperatures. The complex fungal genome—which is larger than that of bacteria and viruses—gives its owners a variety of stress-response tools for adapting to heat that viruses and bacteria may lack. Even slight increases in heat tolerance might allow fungi that were on the cusp of pathogenicity to tolerate our high body temperatures and to proliferate, instead of dying, once they invade. If such scenarios do occur, it would be bad news for humans, given our reliance on body heat as a pillar of our fungal defense.

In addition to the warming climate, the late 1990s saw increased development on the eastern side of Vancouver Island. Forests were logged, an expressway was extended, soil was stirred up and subdivisions were built. Stirring up soil and cutting down trees could have released an organism from a previously small niche into the wider world, Bartlett points out. Emergence of *C. gattii* as a pathogen in that region may have resulted from a serendipitous confluence of factors: several years of warmer winters and drier summers; soil disturbance; and an area popular among both mobile tourists and retirees, who tend to be more susceptible to infection than younger people.

PORTENTS

TO A GREAT EXTENT, we have ourselves to blame for the growing menagerie of pathogenic fungi menacing plants, animals and people—and not only because we have had a large hand in climate change. Many fungi have a home range. Humans have relentlessly helped them escape those homes through international trade. Trade most likely brought the Irish Potato Famine to Europe, chestnut blight to North America and skin-infecting chytridiomycosis to amphibians worldwide. Our shipping addiction has created a de facto fungal dating service. Fungi, as a group, are enthusiastic sexual beings. When humans bring together fungi that were previously separated by geography but still able to mate, the resulting hookups can produce new and more virulent variants that are suddenly able to infect organisms that their ancestors could not or to thrive in new environments. Continuing or increasing trade will boost the odds both of existing fungal pathogens being introduced to naive hosts and of novel pathogens being created via fungal dalliances.

Although very little can now be done to stop *C. gattii*'s spread, we can take steps to reduce the chance that fungi will race through and wreak havoc on unsuspecting populations and to be better prepared when an outbreak occurs. A good place to start would be to improve monitoring and diagnosis of fungal diseases. Because fungal diseases are uncommon in healthy people, doctors may not test for them, leading to a delay in diagnosis and more intractable symptoms when treatment begins. Meanwhile the available diagnostic techniques for many fungi lack specificity or sensitivity, or both, and may be too expensive in impoverished countries. The World Health Organization has no fungal infection program, and few public health agencies, with the exception of the U.S. Centers for Disease Control and Prevention, currently monitor fungal infections.

Another line of defense would be heightened plant and animal biosecurity. Because human pathogens often also live in soil and on plants, increased oversight of the entry of such materials into our country—testing shipments of agricultural products or animals for fungi known to be important human pathogens, for instance, or being more diligent in airport customs about cleaning muddy shoes or outdoor equipment or preventing import of plant material by international travelers, as countries such as Australia and New Zealand do—could not only fight disease outright but also reduce the risk of illicit fungal sex.

More money could be invested in developing new and improved antifungal drugs. A major hurdle is our relatedness to fungi—we are practically first cousins in the tree of life. Fungi and animals parted ways more recently than any other major group of organisms. That kinship not only makes yeast excellent models for mammalian biology but also makes yeast and other fungi more challenging to treat when they infect animals. "The fact that they're [so closely related] is a huge problem because much of their machinery is shared with our own," Heitman says, "so it's harder to find unique targets for antifungal drugs." The drugs we do have are often only modestly effective in reducing deaths from invasive fungal disease, can produce toxic side effects or may interact badly with other drugs. Few new antifungal agents are in the pipeline. Antifungal vaccines offer another line of defense. Few have made it to clinical trials, however, and none are currently medically available for humans. Developing fungal vaccines would be a good insurance policy should the worst come to pass and could help many who are already at increased risk of fungal disease.

The story of *C. gattii* has an ominous footnote. VGIIa and b have now both spread to Oregon, but VGIIc first emerged there in 2005, before the Vancouver Island VGIIa and b had even appeared in the U.S. Extensive tests on samples from Vancouver Island show VGIIc has never been seen there. Genetic analysis of the Oregon VGIIc strain clearly shows it is not the offspring of a simple mating between VGIIa and b. These observations suggest not one outbreak of new hypervirulent *C. gattii* in the Pacific Northwest but two.

"This looks like an outbreak within an outbreak, which may be of independent origins," Heitman wrote in a recent report to the Institute of Medicine. "It is as though two pebbles have been dropped into a pond at different times, one earlier than the other, and they have generated concentric waves that are now expanding outward and intersecting." In other words, the nearly simultaneous outbreak of VGIIa and b on Vancouver Island and of VGIIc in Oregon may be an astounding coincidence, although perhaps both were favored by the same conditions. Such outbreaks were not known before 1999, and now two had occurred within just seven years. This revelation underscores one of the few certainties in the tale of coughing humans, molding bats and blighted trees: underestimating the fungal talent for migrating and thriving on new hosts in our warming and shrinking world is a very bad bet. SA

MORE TO EXPLORE

Global Warming Will Bring New Fungal Diseases for Mammals. Monica A. Garcia-Solache and Arturo Casadevall in *mBio*, Vol. 1, No. 1; April 2010.

Sexual Reproduction, Evolution, and Adaptation of *Cryptococcus gattii* in the Pacific Northwest Outbreak. Joseph Heitman, Edmond J. Byrnes III and John R. Perfect in *Fungal Diseases: An Emerging Threat to Human, Animal, and Plant Health.* National Academies Press, 2011.

Hidden Killers: Human Fungal Infections. Gordon D. Brown, David W. Denning, Neil A. R. Gow, Stuart M. Levitz, Mihai G. Netea and Theodore C. White in *Science Translational Medicine,* Vol. 4, No. 165; December 19, 2012.

SCIENTIFIC AMERICAN ONLINE
Learn more about the how fungi have evolved to elude our immune systems at **ScientificAmerican.com/dec2013/fungal-infection**

PSYCHOLOGY

How Google Is Changing Your Brain

By Daniel M. Wegner and Adrian F. Ward

For millennia humans have relied on one another to recall the minutiae of our daily goings-on.

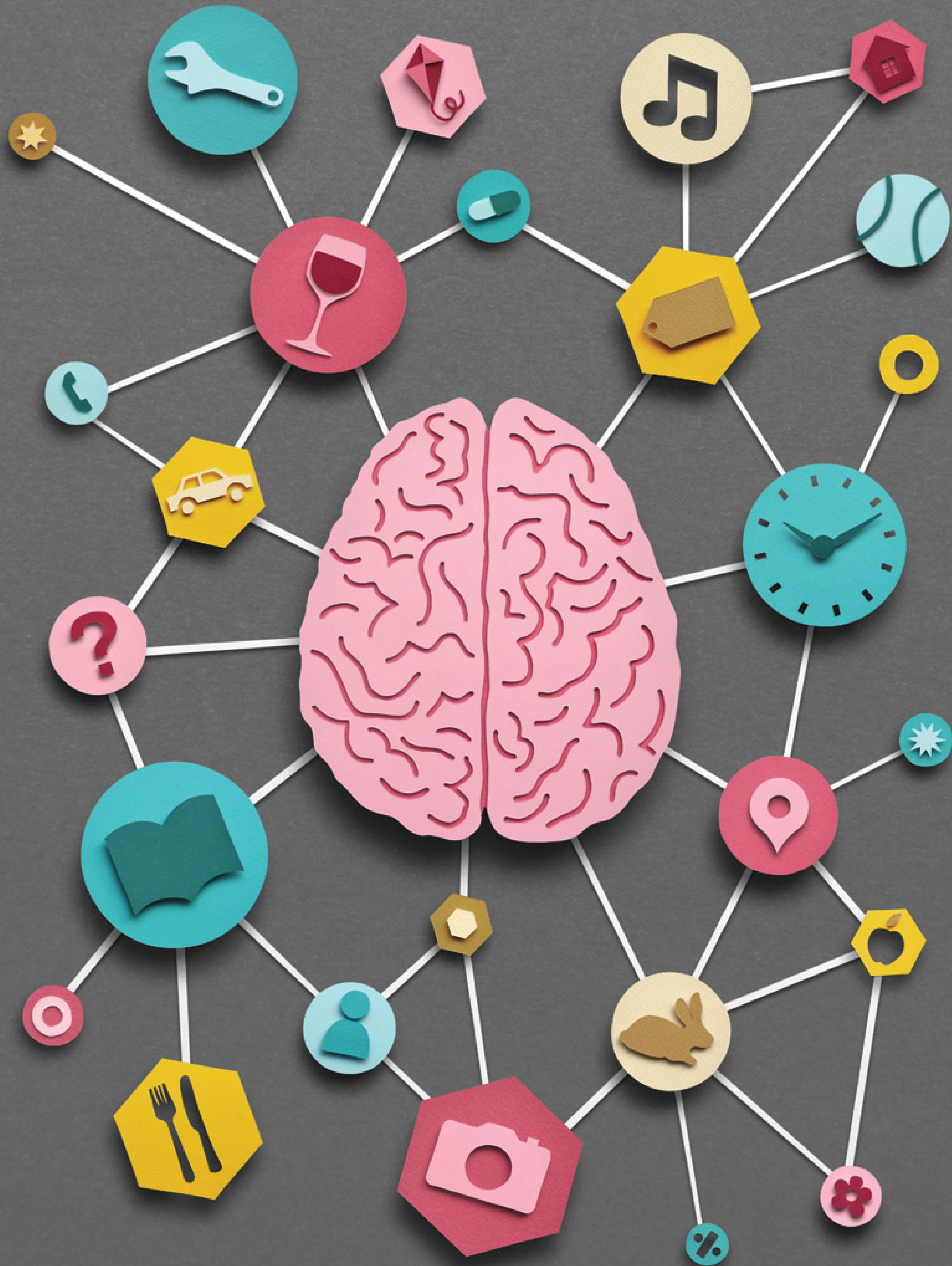
Now we rely on "the cloud"—and it is changing how we perceive and remember the world around us

A couple receives an invitation to a birthday party. Through long experience, each intuitively knows what to do next. One partner figures out whether the dress code is formal or casual. The other makes a mental note of the time and place of the gathering so that they don't forget.

To some degree, we all delegate mental tasks to others. When presented with new information, we automatically distribute responsibility for remembering facts and concepts among members of our particular social group, recalling some things on our own and trusting others to remember the rest. When we can't remember the right name or how to fix a broken machine, we simply turn to someone else charged with being in the know. If your car is making a clunking noise, you call Ray, your gearhead friend. Can't remember who starred in *Casablanca*? Marcie, the movie buff, knows. All types of knowledge, from the prosaic to the arcane, get apportioned among members of the group, whether the social unit in question is a married couple or the accounting department of a multinational corporation. In each case, we don't only know the information stored within our own minds; we also "know" what kinds of information other members of our social group are entrusted with remembering.

This divvying up avoids needless duplication of effort and serves to expand the memory capacity of the group as a whole. When we off-load responsibility for specific types of information to others, we free up cognitive resources that otherwise would have been used to remember this information; in exchange, we use some of these resources to increase our depth of knowledge in the areas for which we are responsible. When group members share responsibility for information, each member has access to knowledge both broader and deeper than could be obtained alone. Distributed memory binds the group together—any one individual is incom-

Illustration by Owen Gildersleeve



plete without being able to draw on the collective knowledge of the rest of the group. If separated, our birthday couple would be at a loss: one partner might wander the streets in top hat and tails while the other would arrive at the party on time wearing a sweatshirt.

This tendency to distribute information through what we call a "transactive memory system" developed in a world of face-to-face interactions, one in which the human mind represented the pinnacle of information storage. Yet this world no longer exists. With the development of the Internet, the human mind has been reduced from a powerhouse to an also-ran.

Inviting the iPhone's Siri into one's social group changes everything. Our work suggests that we treat the Internet much like we would a human transactive memory partner. We off-load memories to "the cloud" just as readily as we would to a family member, friend or lover. The Internet, in another sense, is also unlike a human transactive memory partner; it knows more and can produce this information more quickly. Almost all information today is readily available through a quick Internet search. It may be that the Internet is taking the place not just of other people as external sources of memory but also of our own cognitive faculties. The Internet may not only eliminate the need for a partner with whom to share information—it may also undermine the impulse to ensure that some important, just learned facts get inscribed into our biological memory banks. We call this the Google effect.

A NEW PARTNER

ONE RECENT EXPERIMENT from our group demonstrated the extent to which the Internet is beginning to replace a friend or family member as a companion in sharing the daily tasks of remembering. Betsy Sparrow of Columbia University, Jenny Liu, then at the University of Wisconsin–Madison, and one of us (Wegner) asked participants to copy 40 memorable factoids into a computer (for example: "An ostrich's eye is bigger than its brain"). Half of the people in the experiment were told that their work would be saved on the computer; the other half were told that it would be erased. Additionally, half of each group was asked to remember the information, whether or not it was being recorded by the computer.

We found that those who believed the computer had saved the list of facts were much worse at remembering. People seemed to treat the computer like the transactive memory partners that we started studying decades ago: off-loading information to this cloud mind rather than storing it internally. Strikingly, this tendency persisted when people were explicitly asked to keep the information in mind. It seems that the propensity for off-loading information to digital sources is so strong that people are often unable to fix details in their own thoughts when in the presence of a cyberbuddy.

Another of our group's experiments looked at how quickly we turn to the Internet when trying to answer a question. To test this idea, we used what psychologists call a Stroop task,

Daniel M. Wegner was John Lindsley Professor of Psychology in Memory of William James at Harvard University. He studied transactive memory and thought suppression, among other things. Wegner died in July after a long illness. The American Psychological Society noted that "his memory will live on, not just in the creativity and breadth of his contribution to psychological science, but also in the obvious joy he took from his research, as imparted to his students, and in his writing."

Adrian F. Ward received his Ph.D. in psychology at Harvard with Wegner as his adviser. His dissertation focused on ways people blur the boundaries between the Internet and the self. He is now a senior research associate at the University of Colorado at Boulder.

wherein participants examine a series of words in different colors and must identify the color of each word while disregarding the meaning of the word. By measuring how quickly they name each word's color, we can tell to what extent each word captures their attention. If they are relatively slow to name the color, we assume the meaning of the word is relevant to something they are thinking about. For example, people who have been deprived of food for 24 hours are slower to name the color of a word for a particular food relative to people who are well fed. Because food-related words are relevant to the subjects' current needs, these words are nearly impossible to ignore and consequently elicit slow reaction times.

In our experiment, participants completed two Stroop tasks: one after responding to easy trivia questions and another after trying to respond to hard ones. The words in these Stroop tasks were related either to the Internet—Google in red letters or Yahoo in blue, for instance—or to general brand names—Nike in yellow or Target in green, among others.

AN ALL-KNOWING FRIEND

WE FOUND a particularly striking effect after asking hard trivia questions—that is, questions participants could not answer on their own (for instance, "Do all countries have at least two colors in their flags?"). People slowed significantly in answering the color of Internet-related words but not general brand-related names, suggesting that the Internet comes to mind quickly when people do not know the answer to a question. Apparently, when we are faced with requests for information we do not know, our first impulse is to think of the Internet—our all-knowing "friend" that can provide this information to us after a simple tap of the finger or effortless voice command. As we off-load responsibility for many types of information to the Internet, we may be replacing other potential transactive memory partners—friends, family members and other human experts—with our ever present connection to a seemingly omniscient digital cloud.

In many ways, this transition from distributing information among members of a transactive social network of friends and

IN BRIEF

Remembering is traditionally a social enterprise. One person knows how to cook a turkey. A partner recalls how to fix the leak in the sink.

The Internet changes everything. With nearly ubiquitous online access, many people may first perform a smartphone search rather than calling a friend.

Being online all the time changes the subjective sense of self as borders between personal memories and information distributed across the Internet start to blur.

acquaintances to the digital cloud makes sense. On the face of it, the petabytes dispersed throughout the Internet bear some resemblance to what is in a friend's head. The Internet stores information, retrieves it in response to questions and even interacts with us in surprisingly human ways, remembering our birthday and even responding to voice commands.

In other ways, the Internet is not like any person we have ever met before—it is always present, is always on and knows virtually everything. The information you can get to with a smartphone is vastly greater in scope than can be stored by any single person—or, many times, entire groups. It is always up-to-date, and, barring a power blackout, it is not subject to the distortion and forgetfulness that afflicts the memories ensconced inside our heads.

The Internet's astounding efficiency contrasts sharply with older search methods. Asking friends for information often requires tracking them down, hoping they know the desired fact, and waiting through hemming, hawing and a throat clearing or two as they search their own memories for an answer. Similarly, finding information in a book may involve driving to a library, fumbling through a card catalogue and wandering through shelves before the desired material is finally located. The very act of seeking a fact or quotation from an acquaintance or a reference book emphasizes our reliance on external information sources.

The information retrieved from the Internet now arrives sometimes more quickly than what we pull out of our own memories.

Google and Wikipedia have changed all that. The distinction between the internal and the external—what resides in our minds as opposed to what a friend knows—changes radically when the confidant is the Internet. The information retrieved from the Internet now arrives sometimes more quickly than what we can pull out of our own memories. The immediacy with which a search result pops onto the screen of a smartphone may start to blur the boundaries between our personal memories and the vast digital troves distributed across the Internet. We recently performed experiments at Harvard University to test the extent to which people incorporate the Internet into a subjective sense of self. In this study, we again tried to ascertain how our thoughts turn readily to search engines when confronted with a trivia question. Before conducting the research, we devised a scale measuring how people assess the capability of their own memories. Someone who agrees with the statements "I am smart" and "I am good at remembering things" may be said to have high cognitive self-esteem.

Next we asked people to answer trivia questions with or without the assistance of Google and then asked them to rate themselves on this scale. Cognitive self-esteem was significantly higher for those who had just used the Internet to search for answers. Incredibly, even though answers came verbatim from a Web site, people in the study had the illusion that their *own* mental capacities had produced this information, not Google.

To ensure that people had not felt smarter simply because they were able to answer more questions with the assistance of Google, we followed with a similar study in which those who did not use the search engine received false feedback that they had given the right answers to almost all the trivia questions. Even when participants in both groups believed they had performed equally well, those who had used the Internet reported feeling smarter.

These results hint that increases in cognitive self-esteem after using Google are not just from immediate positive feedback that comes from providing the right answers. Rather, using Google gives people the sense that the Internet has become part of their own cognitive tool set. A search result was recalled not as a date or name lifted from a Web page but as a product of what resided inside the study participants' own memories, allowing them to effectively take credit for knowing things that were a product of Google's search algorithms. The psychological impact of splitting our memories equally between the Internet and the brain's gray matter points to a lingering irony. The advent of the "information age" seems to have created a generation of people who feel they know more than ever before—when their reliance on the Internet means that they may know ever less about the world around them.

Yet perhaps as we become parts of the "Intermind," we will also develop a new intelligence, one that is no longer anchored in the local memories that are housed only in our own brains. As we are freed from the necessity of remembering facts, we may be able as individuals to use our newly available mental resources for ambitious undertakings. And perhaps the evolving Intermind can bring together the creativity of the individual human mind with the Internet's breadth of knowledge to create a better world—and fix some of the set of messes we have made so far.

As advances in computation and data transfer blur the lines between mind and machine, we may transcend some of the limits on memory and thought imposed by the shortcomings of human cognition. But this shift does not mean that we are in danger of losing our own identity. We are simply merging the self with something greater, forming a transactive partnership not just with other humans but with an information source more powerful than any the world has ever seen. SA

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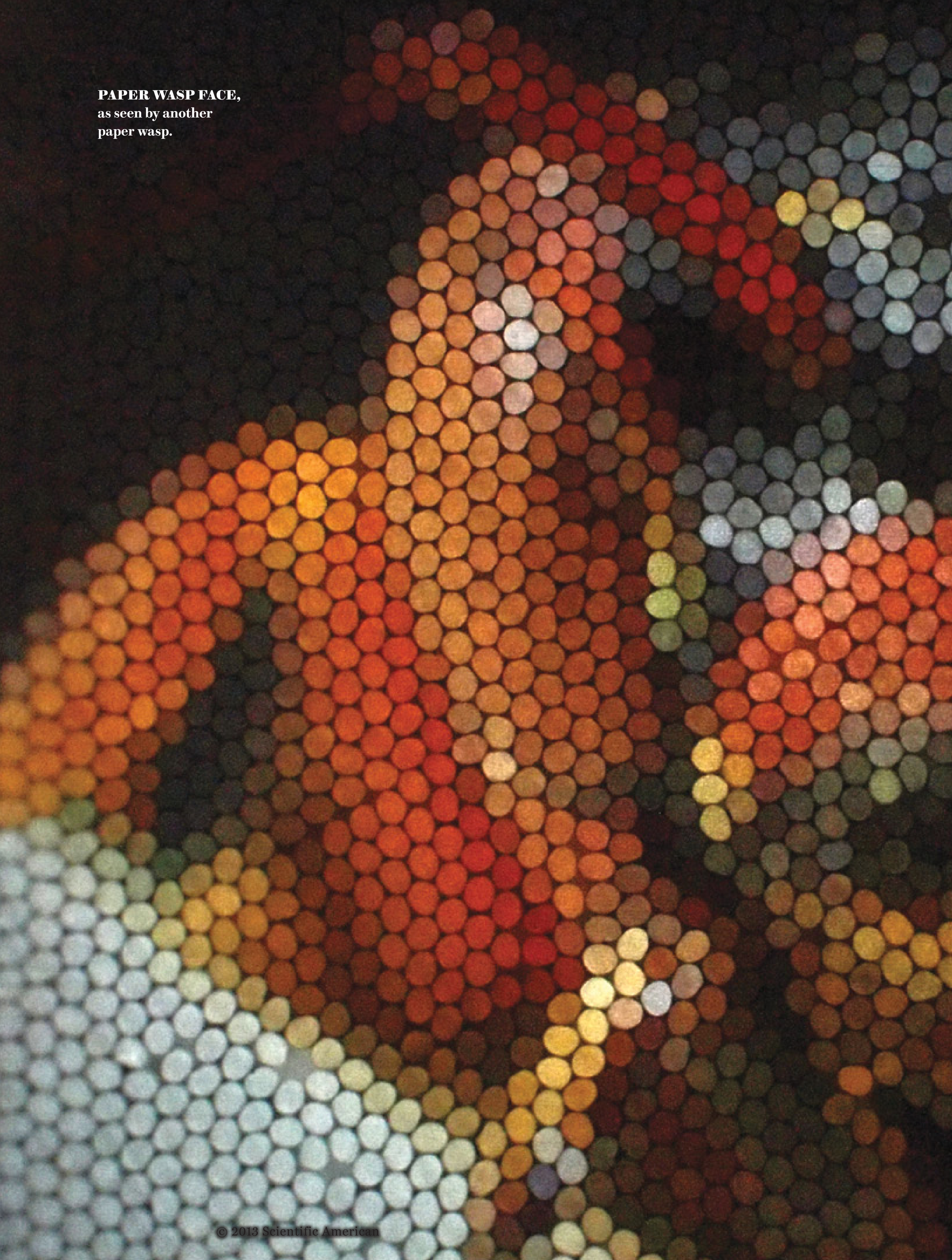
Read a remembrance of the late Daniel M. Wegner from a former graduate student at **ScientificAmerican.com/dec2013/wegner**



PAPER WASP FACE,
as seen by another paper wasp.

ANIMAL BEHAVIOR

GOOD WITH FACES

Conventional wisdom holds that the ability to recognize faces requires a complex mammalian brain. But some insects are surprisingly adept at this task

By Elizabeth A. Tibbetts and Adrian G. Dyer

Elizabeth A. Tibbetts is an associate professor at the University of Michigan. She studies how evolution shapes animal behavior and cognition.

Adrian G. Dyer is an associate professor at RMIT University in Melbourne. He conducts behavioral studies to investigate how the visual systems in different animals process complex information.

The wasps and bees buzzing around your garden might seem like simple-minded creatures. They build nests, forage for nectar, raise their young and then die, their lives typically playing out over the course of a single year or less. Some of these species rival humans and other primates in at least one intellectual skill, however: they recognize the individual faces of their peers.

More specifically, members of a species of paper wasp can perceive and memorize one another's unique facial markings and are able to use this information to distinguish individuals during subsequent interactions, much as humans navigate their social environment by learning and remembering the faces of family, friends and colleagues. Further, even certain insects that do not normally memorize faces in the wild can be trained to do so—and can at times even learn to tell human faces apart.

A popular theory of intelligence holds that the exceptionally large human brain evolved to cope with the challenges posed by having to learn and remember many individuals in complex societies. But the discovery that creatures with a brain less than 0.01 percent as large as our own can also identify individuals is forcing scientists to consider how this startling ability evolved and which features of insect brains make facial recognition possible. The answer to the last question, in particular, could help software designers to improve facial-recognition software.

A FORTUITOUS DISCOVERY

As is often the way with scientific discoveries, the revelation that wasps see one another as individuals resulted from a lucky accident. As a young graduate student in 2001, one of us (Tibbetts) was working on a project focused on detailing the social lives of *Polistes fuscatus* paper wasps. The project involved painting colored dots on their backs, then videotaping colonies and tracking the interactions among the insects. One day Tibbetts accidentally videotaped a colony with two unmarked wasps. The data would be useless unless she could figure out a way to differentiate between the two insects. As she watched the tape, she suddenly realized that she could tell the unmarked wasps apart by looking at the yellow, brown and black stripes and spots that make up their natural facial markings. Could wasps, she wondered, do the same?

Tibbetts couldn't resist checking. She spent the next few days documenting the fantastic diversity of facial patterns in wasps and then tested whether the creatures could use these patterns as a guide to recognizing individuals. Using an extremely high-tech method—applying modeling paint with toothpicks—she changed a wasp's facial features and then observed the social consequences. Aggression is rare in wasp colonies, so if the wasp was treated more aggressively by nest mates after the

IN BRIEF

Until recently, scientists thought that the ability to recognize individual faces required a large mammalian brain.

But studies of paper wasps and honeybees have shown that some small-brained insects can manage this feat, too.

These insects use a face-processing mechanism that is similar to the ones humans use to tell faces apart.

This discovery could aid software developers in their efforts to enhance face-recognition software.

PRECEDING PAGES: COURTESY OF ADRIAN G. DYER AND ELIZABETH A. TIBBETTS

makeover, the behavior shift would be proof that wasps pay attention to faces. As a control, she also applied paint to some insects without changing their appearances to rule out the possibility that the wasps were reacting to some aspect of the paint other than its visual effect. She found that the nest mates displayed far more aggression toward the visibly altered wasps than to the control subjects; for the control wasps, interactions with their nest mates proceeded in a business-as-usual fashion. The results showed that wasps do indeed use variation in facial patterns for individual recognition.

Tibbetts was amazed. To appreciate just how astonishing this finding was, consider how humans recognize faces. First, we must perceive a specific arrangement of unique facial features—such as nose, mouth, eyes and ears—and, in our mind, link the arrangement to more abstract information about the person, such as that he or she is our boss or our neighbor. Then we need to quickly recall that pairing each time we see that particular individual.

Interestingly, we learn faces faster and more accurately than we grasp many other types of complex visual information. For instance: if you go to a party, you can quickly memorize the faces of the attendees without any great effort. It would take substantially more time and effort to learn multiple unique, but visually similar complex patterns such as those used in Chinese script. Both faces and Chinese script are composed of multiple elements that come together into a larger whole, but we are better at learning faces than Chinese script because evolution has furnished us with brain adaptations specifically for learning faces. Indeed, in the human brain a region called the fusiform face area is dedicated to face processing. This processing mechanism is so highly specialized that it fails us if an image is simply turned upside down. Likewise, even small modifications to critical regions of a face, such as the eyes, can hamper our ability to recognize a familiar visage.

Although humans as a species excel at face learning, approximately 2 percent of us have some form of deficit. Most face-learning deficits are thought to be hereditary, although they can also emerge in adulthood after injury to the fusiform face area. Given the importance of social recognition in human societies, such disorders can be debilitating. In some extreme cases, people may even have trouble recognizing their spouses and their children, likening the task to trying to learn the identity of different rocks in the garden. In addition, the impaired social development seen in individuals with disorders such as autism may stem at least in part from face-processing deficits.

Given the importance of specialization to human face learning, Tibbetts pondered whether paper wasps could have independently evolved a similar specialization or whether they instead process faces in a different way. To find the answer, she first needed a reliable method for training wasps to attend to images she deemed “correct” while bypassing incorrect ones. Researchers typically train social insects such as honeybees to perform certain tasks by rewarding them with sugar when they make correct choices. Honeybees are eager to work for sugar because collecting food to share with nest mates is one of their primary jobs. Wasps, however, can survive for weeks without eating, so initial efforts to train them using sugar rewards failed. Tibbetts and her then graduate student Michael Sheehan, now at the University of California, Berkeley, eventually found that they could train the creatures to go to the correct image in a choice between two by delivering a small electric shock to the wasps when they selected an incorrect image.

With the new training technique, wasps learned to differentiate between respective pairs of five different types of images: normal wasp face images, simple black-and-white geometric patterns, whole caterpillars (the wasps’ natural prey), wasp face images with the antennae digitally removed, or scrambled wasp face images. The wasps rapidly and accurately learned to select specific normal faces within only 20 trials but had greater difficulty learning to discriminate among images in the other four pairings. Most strikingly, simply removing the antennae from a wasp face image or rearranging the face components dramatically reduced their impressive face-learning capacity.

The difference in the wasps’ ability to learn normal face images versus antennaeless ones provides very strong evidence that wasps have neural systems specialized for wasp face learning. Antennaeless faces are composed of the same colors and patterns as normal faces, but the wasp visual system does not reliably process and recognize the altered image as a face. The effect of antennae removal on learning indicates that wasps, like people, perceive faces through some kind of holistic processing mechanism.

ILLUSION

Face-Off

The Margaret Thatcher illusion, developed by Peter Thompson of the University of York in England, reveals that face processing in humans is highly specialized. We have trouble recognizing a familiar face when an image is turned upside down and when critical features, such as the eyes and mouth, are inverted. Insects that can learn faces also falter when shown modified images, but whether they process faces just as we do remains to be tested.

COURTESY OF PETER THOMPSON *University of York*

OBSERVATION that individual wasps in the species *Polistes fuscatus* have unique facial markings led to the discovery that the insects use these patterns to recognize individual nest mates and interact with them accordingly. Like humans, the wasps appear to perceive and process a face as a whole, rather than learning each feature separately.

COURTESY OF UNIVERSITY OF MICHIGAN

That is, instead of learning each facial feature separately, element by element, the wasp perceives and processes a face as a whole. Thus, for proper learning to occur, the elements must be intact and correctly arranged. The effect of antennae removal on the wasps' ability to learn faces parallels the way human face learning falters when an image of a face is upside down, image brightness is inverted or facial features are scrambled.

The occurrence of face specialization in both humans and wasps suggests that this mechanism could be more widespread in the animal kingdom than initially thought, evolving when social conditions favor it. In the case of *P. fuscatus,* nests are started by groups of queens that work together to survive. But the queens also compete with one another for reproductive dominance. In such situations, it probably pays for cooperating queens to be able to recognize one another and remember how each individual ranks in the dominance hierarchy, hence the evolution of face specialization in this species. By the same token, the face-specialization mechanism should not be present in animals that do not usually need to differentiate individuals.

To test this hypothesis, Tibbetts and Sheehan measured face learning in a close relative of *P. fuscatus—Polistes metricus—* which has a different social structure. *P. metricus* nests are typically founded by a solitary queen. With only one queen reproducing, group members have little to gain socially by being able to recognize individual faces. Tibbetts and Sheehan had previously shown that *P. metricus* wasps do not vary in their facial markings and do not naturally recognize individuals. They then posited that *P. metricus* also lacks a special cognitive mechanism for processing faces, unlike the more socially complex *P. fuscatus.* Their findings upheld this supposition.

When given the opportunity, *P. metricus* wasps can learn faces, but it is difficult for them, and they learn faces only about as quickly and accurately as other kinds of images. Furthermore, antennae removal has no effect on the speed or accuracy of their face learning, indicating that this species lacks a specialized holistic-type face-processing mechanism. Instead they process faces as they do any other images: as a collection of independently processed features—perhaps like we humans might learn Chinese script.

HOW HONEYBEES SEE HUMANS

GIVEN THAT *P. METRICUS* can slowly learn faces when trained to do so, despite lacking a specialized mechanism for this activity, one might wonder whether insects with small brains have some capacity to also learn faces of an entirely different type of creature: humans. Inspired by the early paper wasp findings, one of us (Dyer), who studies how bees process visual information, became interested in figuring out whether these insects could learn to tell people apart. In this study, he trained common honeybees to distinguish a target face from a so-called distractor face, presenting them with human visages from a standard neuroscience test. The faces are similar enough that human subjects typically make some errors in judgment. The bees received sweet-tasting sucrose solution for making correct visits to a target face and bitter quinine solution for incorrectly choosing a distractor face. Although it took a while for them to catch on, the bees learned to reliably discriminate the pair of target and distractor faces over the course of 50 trials. The bees also learned to select a target face from a group of novel human faces.

Other experiments using this training procedure revealed some striking similarities between honeybee and human face-processing strategies. First, although the bees learned faces slowly as compared with *P. fuscatus* wasps and humans, they were able to develop some ability to process faces holistically, even though they are not hardwired to do so, as *P. fuscatus* wasps and humans are. Second, honeybees were able to learn multiple viewpoints of the same face and interpolate based on this information to recognize novel presentations. For example, after a bee learns the front and side view of a particular face, it will be able to correctly choose a picture of the same face rotated 30 degrees, even if it has not previously seen this particular image. The honeybees' ability to learn faces is particularly unexpected because honeybee society is far simpler than that of the wasps, consisting of a single queen and a mass of essentially identical workers that do the same tasks. Honeybees do not have distinctive facial markings, and their interactions in the hive often rely on complex pheromonal signals rather than visual cues.

The results suggest that this line of research could be a boon to efforts to develop automatic face-recognition systems. Identifying the same face from different angles is often thought to be a difficult task and is one of the major challenges of machine face recognition. But the tiny brains of these bees are much simpler than primate brains, so once we figure out what processing tricks the bees use for solving such complex problems, we should be able to apply them relatively simply to machine vision to enhance face-recognition software.

Taken together, these studies in insects tell us something fundamental about how face recognition may have evolved. The simple system that *P. metricus* wasps and honeybees have that allows them to learn to recognize faces through experience even though they do not normally distinguish among individuals in their everyday lives may be based on the general pattern-recognition abilities these species use during foraging. It may also function as an intermediate step in the evolution of face specialization. When the forerunners of today's *P. fuscatus* wasps found themselves in a novel social environment in which telling individuals apart aided their survival and reproduction, the wasps could learn to identify individuals. Over time natural selection most likely built on that foundation, changing their brain to produce the face specialization that enhanced the wasps' ability to sort friend from foe quickly and reliably. The intermediate system allowed this adaptation to evolve rapidly: *P. fuscatus* and *P. metricus* are closely related, and their last common ancestor would have had the comparatively primitive face-learning system seen in *P. metricus*. Thus, *P. fuscatus*'s biological adaptation to processing faces efficiently must have evolved recently, after its lineage diverged from that of *P. metricus*.

So the next time you are out in your garden, take a minute to appreciate the resident wasps and bees. There is ever so much more going on in their teensy brains than we could have imagined possible. SA

After a bee learns the front and side view of a particular face, it will be able to correctly choose a picture of the same face rotated 30 degrees, even if it has not previously seen this particular image.

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SCIENTIFIC AMERICAN ONLINE
View an image showing how a honeybee sees a human face at **ScientificAmerican.com/dec2013/face-recognition**

Astrophysicists are gearing up to haul in neutrinos from an exploding star in our own galaxy in hopes that the subatomic particles will provide unparalleled insights into the physics of star death

By Ray Jayawardhana

ASTROPHYSICS

COMING SOON: A SUPERNOVA NEAR YOU

IN THE WEE HOURS OF FEBRUARY 24, 1987, ATOP CERRO LAS CAMPANAS IN CHILE, IAN SHELTON DECIDED TO develop the final photographic plate of the night before heading to bed. Shelton, a resident observer employed by the University of Toronto, had been tinkering with a decades-old 10-inch telescope on the mountain, training the little instrument on one of the Milky Way's galactic sidekicks, the Large Magellanic Cloud (LMC). He lifted the photographic plate out of the developing tank and examined it to make sure the three-hour-long exposure had come out well. Then something caught his attention: a curious bright spot next to a familiar spider-shaped feature known as the Tarantula nebula. He wondered what the unusual spot might be and reasoned that it was likely a flaw in the plate itself. But just to be sure, he walked out of the telescope enclosure into the dry mountain air to look up at the sky with his own eyes. He saw a bright star in the LMC that had not been visible the night before. Shelton hurried over to one of the other telescope domes on the ridge to share the news.

As he discussed his puzzling find with astronomers Barry Madore and William Kunkel in the control room, Chilean telescope operator Oscar Duhalde piped in that he had seen the same star a few hours earlier, when he stepped out for a break. Together

Adapted from Neutrino Hunters: The Thrilling Chase for a Ghostly Particle to Unlock the Secrets of the Universe, *by Ray Jayawardhana, by arrangement with Scientific American/Farrar, Straus and Giroux, LLC (US), HarperCollins (CA), Oneworld (UK).*

COURTESY OF NASA/ESA/N. SMITH *University of California, Berkeley* AND HUBBLE HERITAGE TEAM *STScI/AURA*

MASSIVE STAR Eta Carinae, some 7,500 light-years from the sun, will someday explode in a dazzling supernova. Humankind has already seen a preview—in 1843 the tumultuous star flared up to briefly outshine every star in the night sky except Sirius.


Ray Jayawardhana is Canada Research Chair in Observational Astrophysics and a professor at the University of Toronto, where he studies the origins of planetary systems and the formation of stars and brown dwarfs. He is author of *Strange New Worlds: The Search for Alien Planets and Life beyond Our Solar System* (Princeton University Press, 2011).

the four of them decided the "new" star had to be a supernova, an exploding star that could briefly outshine one billion suns. No other type of astronomical object was known to change in brightness so dramatically, from being too faint to register in photographs taken the night before to being easily spotted with the naked eye. That meant Shelton and Duhalde had discovered a supernova in a satellite galaxy of the Milky Way. A few hours later, working independently, an amateur astronomer in New Zealand saw the same thing.

By midmorning, scientists around the world learned about the discovery, tipped off by phone calls from giddy colleagues and a telegram from the International Astronomical Union. Their delight had to do with the fact that "supernova 1987A" (as it came to be known) was the first one observed in our galactic neighborhood since the invention of the telescope nearly four centuries earlier.

Astronomers rushed to employ a mighty suite of optical, infrared and radio telescopes spread across the Southern Hemisphere, as well as x-ray and ultraviolet instruments onboard spacecraft, to watch the momentous event unfolding in the LMC. It was a period of frenzied activity that few scientists had ever experienced. As one ebullient astrophysicist declared, "It's like Christmas."

These investigations of supernova 1987A provided broad support for the scenario that theorists had developed, with the help of complex simulations on supercomputers, for how an aging massive star self-destructs, with its core collapsing into a tightly packed ball of neutrons—called a neutron star—or into a black hole and with its expelled outer layers spreading outward to form a glowing cloud of debris. Yet the celebration was not limited to astronomers. For particle physicists, other observations of the supernova provided important clues to the nature of the ghostly subatomic particles known as neutrinos. Together the diverse studies of the 1987 supernova have built up anticipation of a similar stellar collapse right in our own galaxy—an event that could occur at any time and that should answer lingering questions about star death and the nature of neutrinos. This time neutrino hunters will probably be the first to detect the event.

PHOTON FORERUNNERS

THE LATE JOHN BAHCALL, then at the Institute for Advanced Study in Princeton, N.J., found supernova 1987A so exciting that he was losing sleep. There was a good reason for his excitement: Bahcall knew that the very first, and arguably the most important, harbingers of this cosmic cataclysm must have arrived hours before astronomers spotted the supernova using conventional telescopes. He was well aware that according to theoretical models of stellar evolution, the core collapse at the end of a massive star's life should result in a copious burst of neutrinos, which would flee the detonation site deep inside the star with little impediment. The visible fireworks would appear only later, when the star's outer mantle blew up. Minutes after he heard about supernova 1987A, Bahcall and two of his colleagues got to work to calculate how many neutrinos should have been recorded by the various neutrino detectors on Earth. They determined that the answer should be a few dozen neutrinos and submitted a paper with their conclusion to the journal *Nature* within a week so that their prediction could appear ahead of the actual measurement. [*Editors' note: Scientific American* is part of Nature Publishing Group.]

Meanwhile experimental physicists had begun to search through data recorded at several underground detectors around the world. Their best chance of registering supernova neutrinos was with the Kamiokande experiment in Japan, which consisted of a four-story-tall, cylindrical tank of purified water, surrounded by 1,000 phototubes to register flashes of light produced when neutrinos interacted with water atoms. A failure to measure neutrinos from supernova 1987A could imply a basic flaw in our understanding of how a supernova works.

Sure enough, to the utter relief of scientists the world over, the neutrino signal stood out clearly in the data, leaving no doubt as to its provenance. The phototubes at the Kamiokande detector picked up 11 flashes in a burst lasting several seconds, nearly three hours before the first optical sighting of the supernova by astronomers in Chile and New Zealand. Halfway around the world, a similar neutrino detector located in a shallow salt mine under Lake Erie, not far from Cleveland, registered eight flashes at exactly the same time as Kamiokande. Later, scientists learned that a third, oil-based detector, at the Baksan Neutrino Observatory in the Caucasus Mountains in Russia, had also recorded five neutrinos.

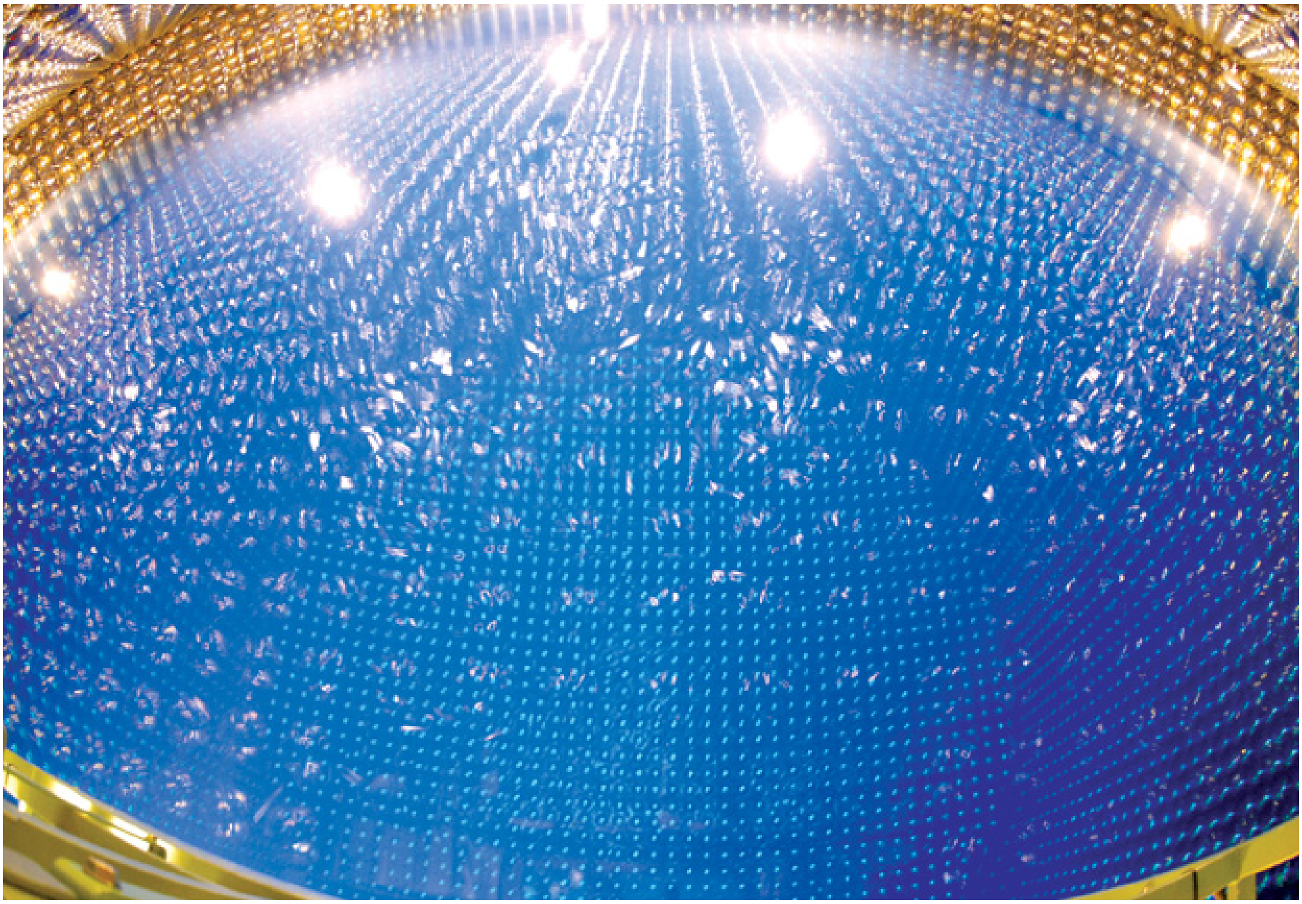
The two dozen neutrinos detected were just a few of the billions on billions of neutrinos sweeping past our planet in a

IN BRIEF

When a star explodes, its bright light alerts astronomers that a supernova is in progress. A supernova also emits vast numbers of neutrinos, which are harder to detect but potentially more valuable.

The last time a supernova went off near the Milky Way, in 1987, physicists detected two dozen neutrinos. Those particles provided critical insights about supernovae and the neutrinos themselves.

The next nearby supernova, which could occur at any time, might be even more spectacular. Advanced detectors may net thousands or even millions of neutrinos, offering a new glimpse into the extreme physics of exploding stars.



DEEP IN A JAPANESE MINE, the Super-Kamiokande detector uses 50,000 metric tons of water to catch neutrinos. Among the many neutrinos passing through Earth, a few collide with the water molecules, creating new particles that give off a flash of light.

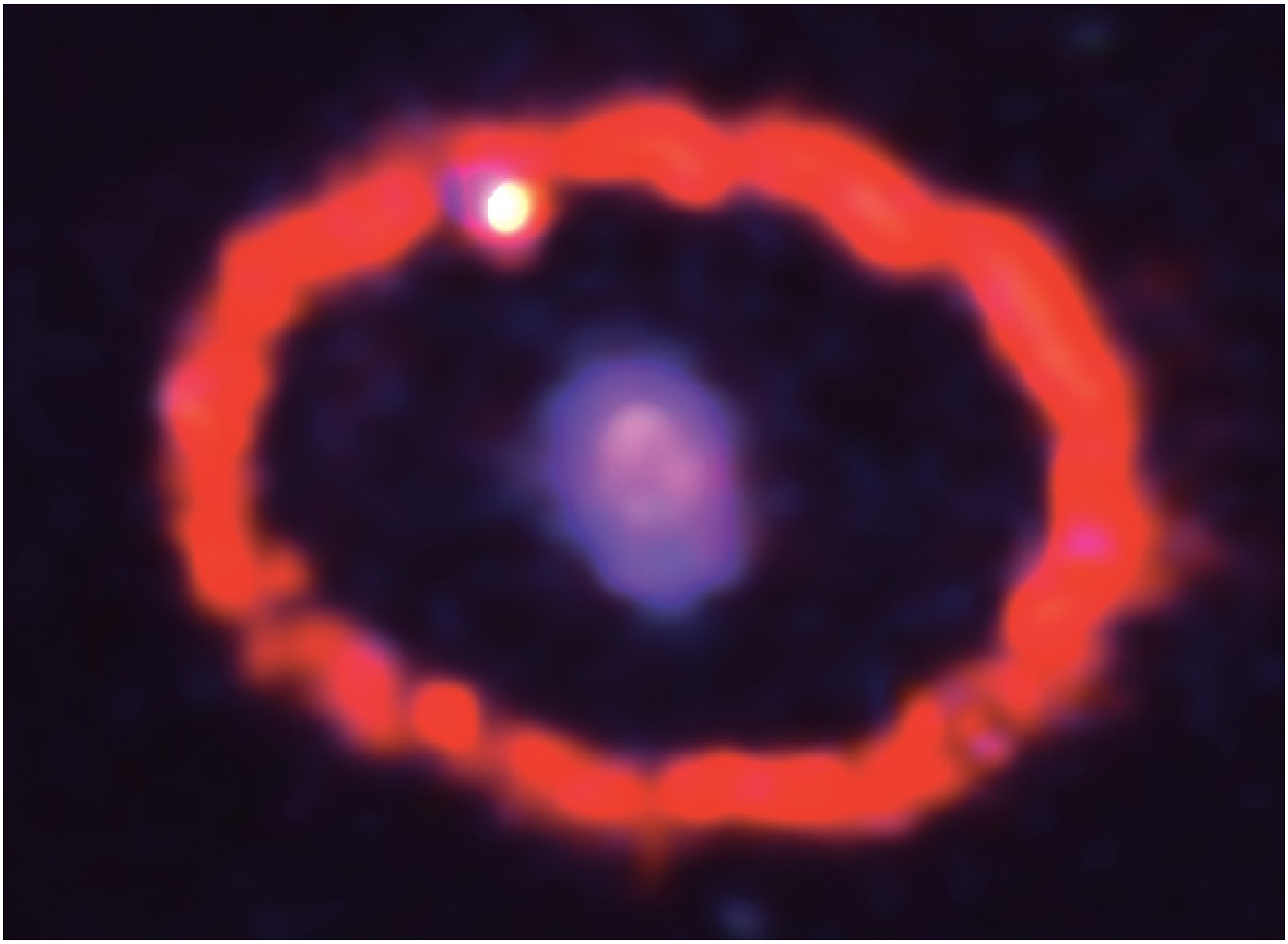
COURTESY OF KAMIOKA OBSERVATORY, INSTITUTE FOR COSMIC RAY RESEARCH AND UNIVERSITY OF TOKYO

burst that originated in the heart of the exploding star in the LMC. Because all three of these neutrino "observatories" are located in the Northern Hemisphere, whereas the LMC is in the south, the neutrinos had to traverse from one side of Earth to the other, through our planet's interior, and enter the detectors from below.

Detecting a grand total of two dozen particles may not sound like much to crow about. But the significance of these neutrino events is underlined by the fact that they have been the subject of hundreds of scientific papers over the years. Supernova 1987A was the first occasion in which we have observed neutrinos coming from an astronomical source other than the sun. As John Beacom, a theoretical physicist at Ohio State University, says, "Neutrinos allow us to see the interior of a massive star at the end of its life, so we can do astrophysics that astronomers could otherwise never do."

The supernova neutrino detections, as sparse as they were, validated some important details of how a massive star blows up. Astrophysicists were pleased to find that the number and energies of the neutrinos they measured agreed with their expectations based on theoretical calculations of the explosion. Thanks to the excellent agreement between theory and observation, researchers concluded that the supernova did not lose energy through some mysterious process—by, say, neutrinos emitting hypothetical particles called axions or leaking into enigmatic extra dimensions. The arrival of neutrinos over several seconds, rather than all in a single burst, confirmed that they took some time to make their way out of the extremely dense shrunken core, as predicted.

Besides, the measurements revealed clues to the nature of neutrinos themselves. Because the neutrinos reached Earth no more than three hours before the supernova was captured in an optical photograph, they must have traveled pretty close to light speed. Lighter particles travel faster than heavier ones, so the scientists reasoned that the mass of a neutrino must be quite small. In fact, based on the particles' arrival time from supernova 1987A, scientists were able to show that despite their prodigious numbers, neutrinos would be unlikely to account for the mysterious "dark matter" permeating the universe. What is more, when a media frenzy broke out in 2011 about neutrinos traveling faster than light, one strong counterargument was based on observations of the 1987 supernova. If these particles indeed travel as fast as the experiment initially reported, the neutrino burst from supernova 1987A should have reached Earth years earlier than the optical light, not mere hours before.



SUPERNOVA 1987A released a staggering number of neutrinos, 24 of which showed up in detectors on Earth. In the mid-1990s material ejected by the supernova collided (*white*) with a giant ring of gas (*red*) that the star had shed some 20,000 years earlier.

COURTESY OF CENTER FOR ASTROPHYSICS, HARVARD UNIVERSITY

GEARING UP

SUPERNOVA 1987A HAS WHET the appetite of astrophysicists who want to learn about the inner workings of dying stars. "Imagine what we could learn if we were to detect 1,000 neutrinos from a nearby supernova," muses Alex Friedland of Los Alamos National Laboratory. Such a prodigious event would not only allow us to pinpoint the sequence of events as the explosion proceeds but would definitively tell us what has become of the ill-fated star. Particle physicists are also interested in neutrinos from supernovae because they provide a rare opportunity to understand how these elusive particles behave under extreme conditions that cannot be replicated in a laboratory.

What both sets of scientists need to achieve their goals is a core-collapse supernova in our own galaxy. Surprisingly, no supernova has been seen in the Milky Way since 1604, when stargazers, including German mathematician Johannes Kepler, noticed a "new star" in the constellation Ophiuchus. At its peak, this supernova was so bright that it was visible during the daytime. Just three decades earlier, in 1572, observers in Europe, including the legendary Danish astronomer Tycho Brahe, had seen another one. Current evidence suggests that both those supernovae resulted from the explosion of a stellar cinder known as a white dwarf, which either gobbled material from a companion star or merged with another white dwarf, rather than from the core collapse of a massive star at the end of its life.

Based on their observations of other galaxies, today's astronomers estimate that at least a few massive stars must explode each century in the Milky Way. Even if interstellar material blocks light from a supernova in the distant realms of our galaxy, it does not hinder the passage of neutrinos, so detecting a burst of neutrinos would reveal the death of a massive star anywhere in the Milky Way. We have had sensitive neutrino detectors operating for about a quarter of a century, and if our estimates are correct, we are due for a galactic supernova any day now. "It would be a once-in-a-lifetime opportunity, so we better be prepared," says Georg Raffelt of the Max Planck Institute for Physics in Munich.

Kate Scholberg of Duke University agrees. She and her colleagues have set up the SuperNova Early Warning System—SNEWS for short—a coordinated network to provide rapid notifications of core-collapse explosions in the galaxy. The plan is that detectors around the globe that are sensitive to supernova neutrinos—such as IceCube in Antarctica, the Large Volume Detector and Borexino in Italy, and a bigger, more sensitive version of Kamiokande, called Super-Kamiokande, in Japan—will report candidate bursts to a central computer at Brookhaven National Laboratory on Long Island. "If several neutrino detectors light up at once, there's a very good chance a supernova has gone off nearby," Scholberg explains.

If the SNEWS computer finds a coincidence within 10 seconds between signals from two detectors, it sends out an alert to observatories worldwide. Scholberg and her colleagues hope that telescopes on the ground and in space will be able to record electromagnetic radiation, including visible light, radio waves and x-rays from the explosion, sooner rather than later and to watch its early stages unravel. "The idea is to have as many people looking as possible, everywhere, to have the best chance possible of pinpointing early light," she says.

"Measuring neutrinos from a galactic supernova will tell us an enormous amount," Scholberg says. "It's an unbelievably rich mine of information." The detectors will record how the number and energy of the arriving neutrinos evolve over time, which will give us insight into how the explosion unfolds. Among other things, scientists will be able to determine whether the star's core collapses all the way into a black hole, from which nothing—not even neutrinos—can escape, or whether it stops short, forging a neutron star instead. If a black hole were to form, the stream of neutrinos racing outward from the supernova would come to a sudden halt. If the end product were a neutron star, on the other hand, the stellar cinder would continue emitting neutrinos for about 10 seconds while it cools down, so the neutrino stream should dwindle slowly instead of cutting off abruptly.

A galactic supernova could also shed light on the nature of the neutrinos themselves. For example, physicists have been struggling to determine what they call the "mass hierarchy" of neutrinos. In effect, they want to know if there are two heavy mass states plus one light state or one heavy and two light states, and they believe that measuring supernova neutrinos would nail down the answer. What is more, in a supernova core the density of neutrinos is so high that interactions among neutrinos, which are otherwise oblivious to one another's presence, could alter their behavior. "We might see some exotic collective oscillations of neutrinos," Scholberg says. "If there are any anomalies in their behavior, they could point to new physics beyond the Standard Model," the well-tested framework of fundamental forces and elementary particles.

Fortunately, several existing detectors are sensitive enough to register neutrinos from a supernova that occurs anywhere in the Milky Way. Super-Kamiokande, for example, would register several thousand hits from a supernova near the galactic center, more than 25,000 light-years away. It could even pinpoint the direction the neutrinos come from to within a few degrees, corresponding to a patch of the sky several times bigger than the full moon. IceCube, which would record a million events, is best for tracking how the neutrino stream evolves with time. "We will be able to see the entire 10-second story of the explosion unfold in snapshots taken every few milliseconds," says IceCube principal investigator Francis Halzen of the University of Wisconsin–Madison. "We will be able to pin down the exact moment that the neutron star forms."

The current detectors, however, are sensitive only to one variety of neutrinos, namely electron antineutrinos. (Neutrinos and their antimatter counterparts each come in three so-called flavors: electron, muon and tau.) "Observing only one flavor is like taking a photograph through a single-color filter," Scholberg observes. She would rather have the full-color view. As a first step toward developing multicolor vision, Scholberg and her Canadian colleagues are building a dedicated apparatus, called the Helium and Lead Observatory (HALO), at the SNOLAB in Ontario. Using 80 tons of lead as the detector material, HALO is sensitive to electron neutrinos, so it will complement other existing detectors that register their antimatter twins. HALO is fairly small as neutrino detectors go, so a supernova would have to explode within the nearer half of the galaxy to be detectable.

WAITING GAME

AS EXCITING AS THE PROSPECTS ARE, realizing them will have to wait until a core-collapse supernova goes off in the galactic neighborhood. The long wait is frustrating. As Ohio State's Beacom says, it is "a matter of holding your breath." The problem is that current observatories are not sensitive enough to detect many neutrinos from supernovae in other galaxies. For example, Super-Kamiokande would register a single paltry event from an explosion in the Andromeda galaxy, the Milky Way's nearest comparably sized neighbor, 2.5 million light-years away.

Although all the evidence suggests that aging, giant stars such as Betelgeuse and Eta Carinae will meet fiery ends in the near future, we do not know when their demise will come. In cosmic terms, "near future" could well be several hundred thousand years from now. That said, the odds are pretty good that a massive star somewhere in the galaxy will explode in the next few decades. As Los Alamos National Laboratory's Friedland has told me, "If I had to bet on what would happen first, the next galactic supernova or building the next big particle collider in the U.S., my money would be on the supernova." Even if the supernova is so far away from Earth that we cannot observe its light through the dusty veil of the Milky Way, it will shine brightly in the neutrino detectors around the world. It will be a sensational event, a watershed moment that neutrino hunters will celebrate like none other. SA

MORE TO EXPLORE

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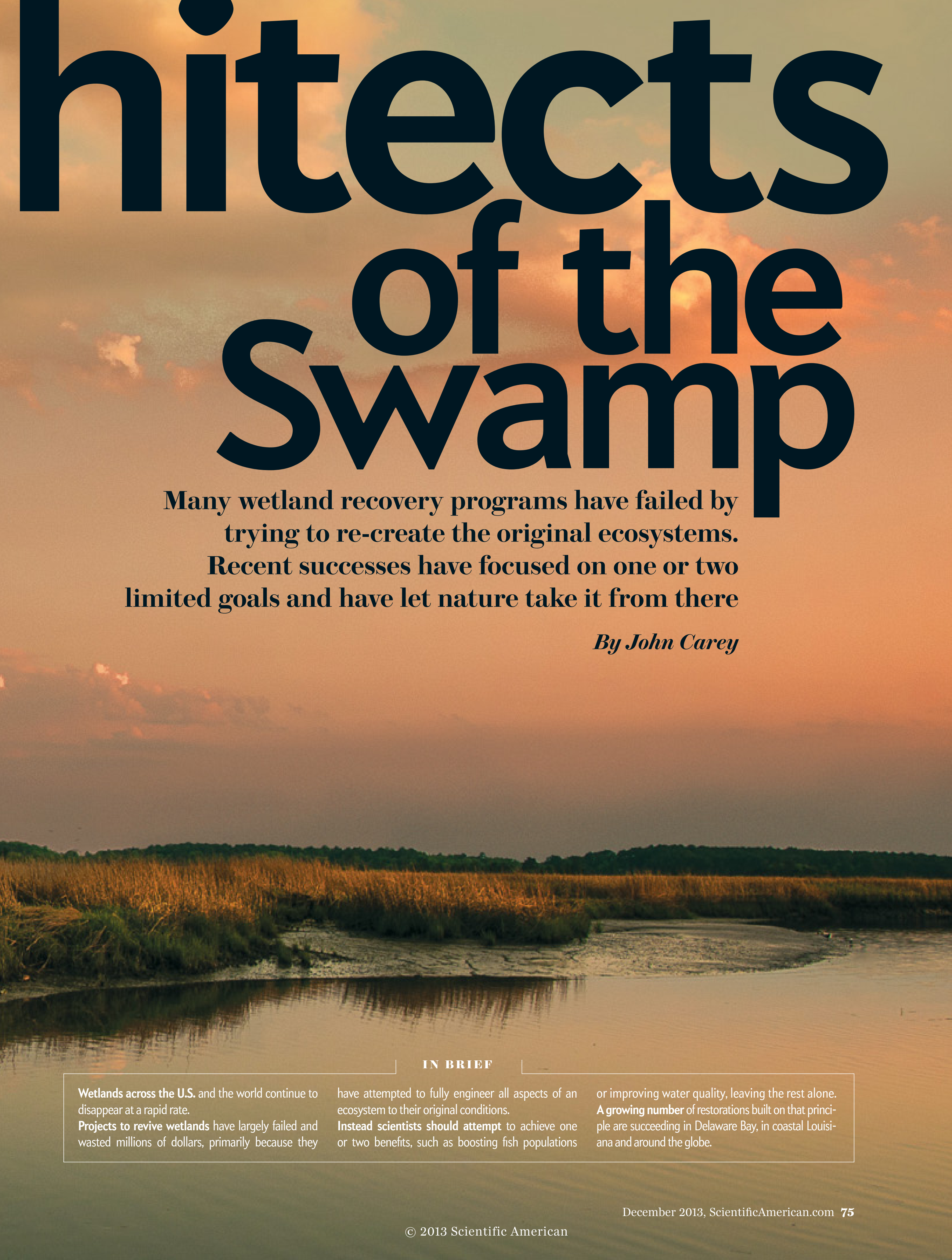
SCIENTIFIC AMERICAN ONLINE
For a slide show of neutrino observatories around the world, go to **ScientificAmerican.com/dec2013/neutrino**

ENVIRONMENT

Arc

DELAWARE BAY: After engineers improved freshwater creeks flowing into a tattered salt marsh so more fish could thrive, nature rebuilt dying plant life into thick, healthy vegetation.



hitects of the Swamp

Many wetland recovery programs have failed by trying to re-create the original ecosystems. Recent successes have focused on one or two limited goals and have let nature take it from there

By John Carey

IN BRIEF

Wetlands across the U.S. and the world continue to disappear at a rapid rate.

Projects to revive wetlands have largely failed and wasted millions of dollars, primarily because they have attempted to fully engineer all aspects of an ecosystem to their original conditions.

Instead scientists should attempt to achieve one or two benefits, such as boosting fish populations or improving water quality, leaving the rest alone.

A growing number of restorations built on that principle are succeeding in Delaware Bay, in coastal Louisiana and around the globe.

John Carey, a former senior correspondent for *BusinessWeek*, is a freelance writer who covers energy and the environment. He wrote about rapid climate change in the November 2012 issue of *Scientific American.*

JOY ZEDLER CAREFULLY PLANNED THE THREE EXPERIMENTAL WETLANDS AT THE University of Wisconsin–Madison's Arboretum to be identical: parallel marshes 295 feet long and 15 feet wide, carved by engineers into the green landscape. Zedler's contractors planted all three tracts with similar species to see how the vegetation would absorb and clean water runoff during storms.

Zedler's team also allowed the same amount of water to flow into the test beds from a pond at the front ends of the tracts. They planned to measure the nutrients in the water entering each plot and draining into a basin at the far end, as well as soil stability, water absorption, and the productivity and diversity of the grasses and other plants. The scientists expected that each of the three wetlands would behave similarly.

The stakes were higher than for the typical university project. The city of Madison was keenly interested because it wanted to learn how to use wetlands to slow and cleanse storm water pouring out of town into neighboring Lake Wingra, which is suffering from high levels of nutrients such as nitrogen and phosphorus in the runoff. And the question of how to maximize the many valuable so-called ecosystem services that wetlands can provide, from reducing runoff and flood damage to boosting biodiversity, has been growing more urgent by the year as wetlands worldwide vanish at an alarming rate. Zedler, a professor of botany and restoration ecology at the university, had hoped the experiment would provide some insight.

Three years later, however, it was clear that the experiment had raised new questions the researchers had not anticipated. "Nothing about the system behaved as we supposed," Zedler says. The first surprise: even though the tracts were just three feet apart and had been planted and expected to develop similarly, one plot became dominated by cattails, whereas the other two blossomed with up to 29 plant species. Second, although the cattail plot produced more plant material overall, it was lousy at everything Zedler expected from lush growth. It did not slow floodwater or control soil erosion. It did not absorb much of the nutrients in the water. The other two tracts provided more of the expected benefits—except for high productivity.

Why the surprising differences? Zedler's team discovered that a layer of clay under the cattail marsh was slightly thicker and thus less permeable than the layer under the two adjacent plots—so water ponded instead of percolating into the ground. That allowed storm water and nutrients to race down the channel. Meanwhile the cattails shaded out soil-stabilizing moss—which grew well in the neighboring swales—so soil erosion was higher.

Zedler's unforeseen results are helping her and other experts explain why the track record of past restoration efforts is poor, and they are pointing the way to improving the success rate. The big lesson from multiple investigations is to forget about trying to re-create a fully functioning wetland that is identical to the one being lost. "We don't know how to do it," says Doug Wilcox, professor of wetland science at the College at Brockport, S.U.N.Y. There are too many variables.

Instead scientists should focus on one or two key objectives, such as rebuilding land, improving water quality or boosting fish populations, and engineer the system to optimize those objectives. Then, once the basic engineering is done, let nature fill in the details as it pleases.

Another lesson is to monitor wetland projects for years, as Zedler continues to do with her experiment. That time is needed to uncover the often surprising details of what works and why and to take corrective action when necessary. Unlike cars, "wetlands do not come with repair manuals," Wilcox says.

Accepting the notion that we usually cannot restore wetlands to their original state is a sobering reminder of the limits of science. But achieving one or two goals can be a major step forward. Inspiration is coming from a growing list of successful projects, from Delaware Bay and the Mississippi River Delta to Iraq and the Guyana coast. "Restoring is a heck of a lot better now than it used to be," says William J. Mitsch, director of the Everglades Wetland Research Park in Florida.

NATURE'S KIDNEYS

RECENT SUCCESSES ARE WELCOME NEWS because wetlands are so valuable. Mitsch calls them "nature's kidneys" and "ecological supermarkets, where all the critters go to eat or be eaten." Michael Weinstein, a senior scientist at the New Jersey Institute of Technology, has a bumper sticker that says "No wetlands, no seafood," and he has proved that the food chain born in marshes extends vital links far out into offshore waters. "They really are our support systems," he says.

Wetlands are our protectors, too. Events such as superstorm Sandy woke many people to the fact that "doing away with

PRECEDING PAGES: DIANA KEHOE *Getty Images*

WILD SANDHILL CRANES exit a pond that collected rainwater early in the design of an experimental wetland at the University of Wisconsin–Madison; urban runoff allowed into the pond led to an unexpected invasion of cattails (*dark green*).

COURTESY OF JOY ZEDLER *University of Wisconsin–Madison*

marshes and dunes was a stupid idea," says John M. Teal, salt marsh expert and scientist emeritus at the Woods Hole Oceanographic Institution. The mere remnants of salt marshes in Long Island's Jamaica Bay helped to dissipate the storm's fury there, for instance, whereas the complete lack of wetlands around Manhattan left it exposed to the raging sea. Wetlands also soak up the nutrients that run off farmlands and down rivers and that fuel harmful algal blooms and oxygen-free dead zones in the nation's coastal waters. They tame floods. Moreover, Mitsch says, "they are probably the best system on the planet for sequestering carbon" in the forms of thick vegetation and rich organic soil.

Yet wetlands have been disappearing fast. The soggy ecosystems have been drained to grow corn in Iowa and salt hay in Delaware, flooded to create fish and shrimp ponds in Thailand, filled to build airports and cities across the globe, and starved of their needed river sediments by levees everywhere. Mitsch estimates that wetlands once covered 4 to 6 percent of the earth's land surface—and fully half of them have already been lost.

Concerted efforts are being made to stem the tide. Jessica Bennett Wilkinson, senior policy adviser for mitigation at the Nature Conservancy, calculates that $3.9 billion a year is laid out in the U.S. on wetlands under section 404 of the Clean Water Act alone. The act requires developers or others who destroy wetlands to restore them or to create compensatory ones.

Much more money is spent around the world on projects such as planting mangrove trees. Unfortunately, the evidence suggests that the money is not being well spent; for example, 90 percent of efforts to rebuild mangrove swamps fail, estimates Robin Lewis, president of consultation firm Lewis Environmental Services. "We're talking millions and millions of wasted dollars every year doing bad projects—and we have very similar failures with all wetland types," he says. A recent analysis of 621 restored wetlands, led by wetland ecologist David Moreno-Mateos, then at Stanford University, shows that restorations fall far short in providing the full functions of equivalent natural wetlands—even after 50 to 100 years.

One reason for the poor success rate is a chasm between biology and engineering. "The guy in the biology department is doing one thing, and the guy in engineering is doing another, and they're both part right and half wrong," Mitsch says. A related criticism of work conducted by the U.S. Army Corps of Engineers, which oversees the vast majority of federally funded restorations, is that engineering often neglects biological realities.

Most fundamentally, efforts founder on the lack of detailed knowledge that Zedler, Wilcox and others are painstakingly gaining. "My irritation is that people have been funded to do wetland restoration without ever developing the methods, first, to do it the right way," Wilcox says.

GET THE WATER RIGHT

SO HOW CAN WE DO IT BETTER? In every project, the starting point is to focus work on one or two benefits. Then select one primary technique to achieve that objective. One of the most fundamental techniques might seem obvious but is often not taken seriously enough: get the water conditions right. "It's not rocket science," Lewis says. "It's hydrology, hydrology, hydrology."

In some rare cases, simply bringing water back works magic. Because of wars, dams and Saddam Hussein's effort to rob opponents of their livelihoods, 90 percent of the 7,700 square miles of marshes in southern Iraq were destroyed by 2000. After Hussein was deposed in 2003, a pioneering project, Eden Again, began to return the water from the Tigris and Euphrates rivers. The marsh bloomed. Thousands of former residents returned to raise water buffalo, harvest fish and weave mats from the reeds. The marsh's survival, though, is tenuous; a dam being built on the Tigris in Turkey could cause new water shortages.

Getting the water conditions right is crucial for rebuilding mangrove swamps, now being lost at a rate of more than 250,000 acres a year worldwide, Lewis says. Here the limited goal is to help trees thrive so they can cut down storm surges and high tides. Any other benefits that might accrue are bonuses.

In the old, standard approach, a project team builds a nursery, grows thousands of seedlings and plants them on coastal mudflats. "These projects are called successful, but in three to five years the [trees] are all gone," Lewis says.

Too much water is the usual culprit. "A mangrove actually spends most of its time out of the water," Lewis explains. "That's something people didn't understand for decades." When restoration expert Jamie Machin arrived in Guyana in July 2012, then as team leader for development consultation company Landell Mills, he measured the tide levels at the sites of a number of failed past projects. The shore bottoms were, on average, 20 inches too low; tree bottoms and roots spent too much time in saltwater, which slowly killed them.

Machin worked with a government team to build structures called groins and to plant *Spartina* grass, which together will trap sediment and raise the mudflats, reducing the time in which the trees are inundated. That single step should also eliminate expensive replanting of seedlings; as nearby trees grow, they will produce propagules—tiny, pod-enclosed living trees—that drop into the water and float around, colonizing new shores. "Once the sediments are built up, there are enough propagules in the system so the mangroves will come back," Machin says. There is no need to engineer a fully functioning ecosystem.

Similarly, Lewis is rescuing 1,000 acres of mangrove swamp in the Rookery Bay National Estuarine Research Reserve in southwestern Florida. A shore road built in the 1930s cut off much of the natural tidal flow to the area. Heavy rains also now fill the swamp like a bathtub, choking the trees. To fix the hydrology, Lewis is planning to install big culverts under the road and clean out cluttered tidal creeks so that heavy rains can quickly drain and Gulf waters can swirl in and ebb out. The main goal, again, is simply to keep the trees from dying. Yet ancillary benefits have already arisen; measurements show that the first six-acre phase of the project has not only improved the health of the mangroves but also brought substantial increases in the number of fiddler crabs and snook. When the entire project is done, "we'll get extremely valuable fish populations restored to areas where they don't exist today," Lewis says.

As the Guyana and Florida cases show, nature can do a great deal of restoration once the water conditions are fixed. In other cases, nature needs more help. The main reason for the loss of tens of thousands of acres of sedge-grass wetlands once dotting the shores of Lake Ontario has been a policy of holding water back behind dams to keep lake levels high for shipping and hydropower. Without periods of low water, encroaching cattails wipe out the highly diverse sedge-grass ecosystem. Regulators are now considering a new policy of allowing lake levels to drop more during times of naturally low water.

The goal of bringing back the sedge grass determined the second vital step: knocking back the cattails. Wilcox and his students are cutting down the cattails in the spring—just after the plants have used stored energy to grow tall but before new photosynthesis can replenish the reserves. They then use herbicide to kill any new shoots that appear.

TORN SALT MARSH in Delaware Bay (*top, 1998*) was restored by cutting a few gaps in adjacent dikes so freshwater could flow in and naturally create tidal creeks, which allowed plants to reseed and flourish (*bottom, 2013*).

COURTESY OF PSEG

A SUCCESS STORY

FOCUSING ON ONE MAIN OBJECTIVE has paid off handsomely in Delaware Bay. The estuary was once lined with salt marshes, an ecosystem teeming with crabs, fish and other aquatic life. Dutch settlers, however, built dikes and drained thousands of acres to grow salt hay for animal feed. Today salt-hay farms still produce weed-free mulch and material for coffin mattresses.

Looming on the New Jersey shore of the bay is the Salem nuclear power plant, owned by utility giant PSEG. The plant sucks in billions of gallons of water a day for cooling and kills millions of tiny fish and other creatures as they get drawn through the intake valves. In the early 1990s state regulators asked PSEG to build cooling towers to end the carnage. Reluctant to spend $1 billion to $2 billion, the utility proposed an alternative: restore enough salt marsh to compensate for the loss of fish—more than 10,000 acres.

PSEG's environmental project manager at the time, John Balletto, brought in a dream team of restoration experts. They determined that the best way to boost the fish populations was to cut gaps in the dikes that would let just the right amount of water into the marsh to create a maze of primary and secondary tidal creeks, which had vanished. It was important not to do too much. "If you engineer a drainage system in great detail, the system is forced to go the way you think it ought to be," explains Teal, one of the consultants. "But if you allow it to develop itself, it's more likely to be stable."

The team dug the main channels and a few side branches and left the rest of the creeks to develop on their own. The scientists' faith that nature would quickly reseed the entire marsh was proved correct. Today the increase in fish populations more

Disappearing Act

50% Wetlands lost in North America, Europe and China since 1900	**8.9 million** Acres of mangroves lost worldwide since 1980
252,000 Acres of mangroves lost globally every year	**74%** Vegetation in restored ecosystems versus naturally healthy sites

SOURCES: "STRUCTURAL AND FUNCTIONAL LOSS IN RESTORED WETLAND ECOSYSTEMS," BY D. MORENO-MATEOS ET AL., IN *PLOS BIOLOGY*, VOL. 10, NO. 1, ARTICLE NO. E1001247; JANUARY 24, 2012 (*top left* and *bottom right*); "THE WORLD'S MANGROVES 1980–2005," BY FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2007 (*top right* and *bottom left*)

than makes up for the losses from the power plant's water intakes. And the restoration looks indistinguishable from adjacent natural marshes, Teal says, even though the main purpose was to create a better environment for fish.

PSEG continues to monitor the marshes and fix problems that pop up. "We're still doing follow-ups at 20 years," Teal says. "In most restorations, people go back one year and maybe the third year, and that's it." Doing it right is expensive; the total cost to date has been more than $100 million. But that is far less than the $1 billion or more for cooling towers.

THE HIMALAYAS OF ECOSYSTEM SERVICES

SUCCESSFULLY RESTORING THOUSANDS of acres of Delaware Bay salt marsh is one thing. But can scientists reverse what National Wetlands Research Center director Phil Turnipseed has called "the greatest environmental, economic and cultural tragedy on the North American continent"—Louisiana's coastal land loss? Experts say that more than 1,800 square miles of marsh have disappeared there in the past 80 years.

We may soon find out.

The state has created a 190-page Louisiana Comprehensive Master Plan for a Sustainable Coast to restore dying wetlands and to build new ones, mainly by diverting sediment-laden Mississippi River water into marshes and shores. And because the region expects to receive billions of dollars from oil giant BP as compensation for the Deepwater Horizon oil spill, "there is now both a plan and money, which has never happened before," says Steve Cochran, director of Mississippi River Delta restoration at the Environmental Defense Fund.

The plan obeys the lesson of focusing on one goal: rebuilding and sustaining hundreds of square miles of land. But the scale is orders of magnitude larger than anything previously attempted. Get it right, and there is a chance to protect an entire coast from storms while revitalizing a vast and richly productive region that John Day, professor emeritus of coastal ecology at Louisiana State University, calls "the Himalayas of ecosystem services." Get it wrong, and with sea-level rise, Gulf waters could turn New Orleans into a modern-day Atlantis and permanently flood out hundreds of thousands of people on the tattered coast. "We can't afford to get it wrong," Day says.

The poster child for successful restoration is the Wax Lake Delta, an expansive area of new marshland created southwest of Morgan City, La., after the army corps began to divert sediment-laden water from the Atchafalaya River in 1942. "It's a beautiful area, with wonderful patterns and variations and willows on the banks," says Denise Reed, chief scientist at the recently formed Water Institute of the Gulf in Baton Rouge, La. "The soil is really firm—you can jump up and down on it."

Reed and other scientists who devised the master plan estimate that similar diversions can build 300 square miles of new wetlands in 50 years. Skeptics, such as Gene Turner of Louisiana State University, say that figure is wildly optimistic, however. He maintains that even when conditions are perfect for land building, the historical record shows a gain that is only about one fiftieth of that calculated by the master plan's models. Some smaller test diversions that have been in place for a decade or more show no gains at all. "They may be wasting a lot of resources on projects that are proved to be wrong," he says.

Turner is in the minority. The data do, however, show that providing the correct type and amount of sediment is crucial. The Wax Lake Delta is built on a foundation of sandy mineral sediment 6.5 to 13 feet thick—which typically comes from deep cuts in a river levee. A shallower cut will divert only finer-grained organic sediment, which is more likely to wash away in the next hurricane. A further complication is that the Mississippi River is flush with nutrients from midwestern farms, which will allow plants to thrive in the newly created marsh without putting down deep, soil-stabilizing roots—making the fragile land vulnerable to storms. That is why Turner and others favor an alternative to diversions: filling in canals dug by oil companies with the dredged material along the canal banks to slow encroaching seawater, helping plants grow.

Whether massive sediment diversions will succeed or fall short "is a hot and heavy controversy, with some legitimacy on each side," Cochran says. Yet time is running out. Most scientists agree that the effort must start now, or else there will not be any natural wetlands left to reconstitute; the delay would also mean no chance to learn from, or adjust to, any stumbles.

Just as a slightly thicker layer of clay made all the difference in Zedler's tiny Wisconsin wetlands, details will determine the results in Louisiana and other restoration projects around the world. And although the challenges are still daunting, Zedler is encouraged that scientists have come a long way in understanding what they need to do. "We can't turn back the clock," she says, "but we also can't stop trying." SA

MORE TO EXPLORE

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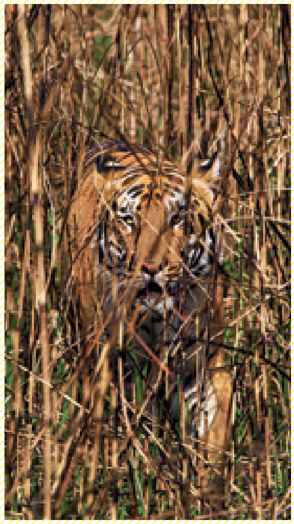
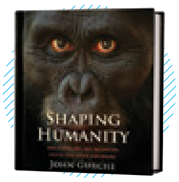
SCIENTIFIC AMERICAN ONLINE
Read about the fight to save wetlands by filling in old oil industry canals at ScientificAmerican.com/dec2013/carey

Tigers Forever: Saving the World's Most Endangered Big Cat

by Steve Winter, with Sharon Guynup. National Geographic Books, 2013 ($40)



A hundred years ago about 100,000 tigers lived in the wild. Today some 3,200 individuals remain. Drawing on a decade of tracking tigers throughout Asia, Winter's photographs and Guynup's prose bring readers close—sometimes uncomfortably close—to these creatures and those who fight their extinction. Tucked between beautiful images of the great cats playing and bathing, we find heartbreaking photographs of slain tigers, orphaned cubs and a distressed puppy kept as bait in a poacher's snare. Poachers, the authors explain, sell tiger parts on the black market, often for use in traditional Chinese medicine. Through its portrayal of tigers struggling for survival in a hostile world, *Tigers Forever* is both a call to action and an indictment of human greed.

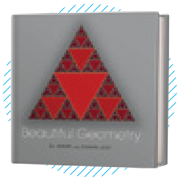


Shaping Humanity: How Science, Art, and Imagination Help Us Understand Our Origins

by John Gurche. Yale University Press, 2013 ($49.95)

How can we paint a picture of someone who lived and died six million years ago, informed by little more than crude artifacts and rare, incomplete skeletal remains? Modeling the dawn of humans through our ancestors' appearances and behaviors is much more than simple guesswork. *Shaping Humanity* reveals the secrets of how artist Gurche reconstructs our early primate ancestors from mere bone fragments. Using gorgeous illustrations and photographs, he describes exactly how he draws from studies of modern-day musculature and even his own facial features to turn crumbling skeletons into the evocative sculptures and images that have appeared in museums, magazines, journals and textbooks worldwide.

—Rachel Feltman



Beautiful Geometry

by Eli Maor and Eugen Jost. Princeton University Press, 2014 ($24.95)

Mathematicians sometimes compare well-constructed equations to works of art. To them, patterns in numbers hold a beauty at least equal to that found in any sonnet or sculpture. In this book, Maor, a math historian, teams with Jost, an artist, to reveal some of that mathematical majesty using jewel-like visualizations of classic geometric theorems. Often the pictures are actually puzzles to be solved, containing clues for perceptive readers to follow. Mixing equal parts math, history and philosophy, the authors begin with some basics—the Pythagorean theorem, the golden ratio, Fibonacci numbers, and so on—before expanding to introduce more baroque and contemporary theorems. The result is a book that stimulates the mind as well as the eye.

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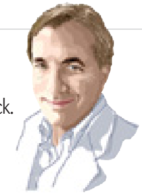
Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His book *The Believing Brain* is now out in paperback. Follow him on Twitter @michaelshermer



Is God Dying?

The decline of religion and the rise of the "nones"

Since the early 20th century, with the rise of mass secular education and the diffusion of scientific knowledge through popular media, predictions of the deity's demise have fallen short, and in some cases—such as in that of the U.S.—religiosity has actually increased. This ratio is changing. According to a 2013 survey of 14,000 people in 13 nations (Germany, France, Sweden, Spain, Switzerland, Turkey, Israel, Canada, Brazil, India, South Korea, the U.K. and the U.S.) that was conducted by the German Bertelsmann Foundation for its Religion Monitor, there is both widespread approval for the separation of church and state, as well as a decline in religiosity over time and across generations.

In response to the statements "Only politicians who believe in God are suitable for public office" and "Leading religious figures should exercise an influence on government decisions," even in über-religious America only 25 percent agreed with the former and 28 percent with the latter. All other countries reported lower figures (with Spain at or near the bottom at 8 and 13 percent and Germany in the middle at 10 and 21 percent, respectively). Moreover, most of the countries in the survey showed a declining trend in religiosity, especially among the youth. In Spain, for example, 85 percent of respondents older than 45 reported being moderately to very religious, but only 58 percent of those younger than 29 said they were. In Europe in general, only 30 to 50 percent said that religion is important in their own lives.

Why the decline? One factor is the dramatic spread of democracy around the globe over the past half a century. Most people surveyed agreed that democracy is a good form of government, with no differences across religious faiths. One of the features of a democracy is the disentanglement of the sacred from the secular because in religiously pluralistic countries no one can legitimately claim special status by faith membership. Democracies also have higher literacy rates and mass education that lead to a tolerance for the beliefs of others that, in turn, lowers the absolutism most religions in the past required, thus undermining the truth claims of any one religion over others.

A second factor is the opening up of economic borders, such as between member nations of the European Union, which replaces zero-sum religious tribalism with nonzero financial exchange. Free trade and the division of labor constitute the greatest generator of wealth in history, and according to the Religion Monitor report using the survey data, "socioeconomic well-being generally results in a decline in the social significance of religion in society and a decrease in the numbers of people who base their life praxis on religious norms and rules." Why? One of the social functions of religion is to help the poor, so as a country's impoverished declines (and, as in Sweden and other European countries, government social programs aid the poor), so, too, does religiosity. And because the middle classes of most countries are growing from the youth up, that could explain the report's assessment that "almost all the countries in the study … exhibit a decline in the centrality and significance of religion for daily life from one generation to another. As a general rule, the younger people are, the lower their religiosity."

Nevertheless, the authors caution about drawing the Nietzschean conclusion that God is dead: "This does not mean that religiosity and religious behaviour have vanished or will vanish completely from people's lives: between 40% and 80% of European citizens exhibit at least a medium degree of religious belief according to the centrality index of religiosity." Still, the trend is unmistakable in another statistic from the study. The percentage of people who said that they are "not religious or not very religious" is significant, and the figure for the U.S. (around 31 percent) matches that of other studies.

A 2012 Pew Research Center survey, for example, found that the fastest-growing religious cohort in America are the "nones" (those with no religious affiliation) at 20 percent (32 percent of adults younger than 30), broken down into atheists and agnostics at 6 percent and the unaffiliated at 14 percent. The raw numbers are staggering: with the U.S. adult population (age 18 and older) at 240 million, this figure translates into 48 million nones, or 14.4 million atheists/agnostics and 33.6 million unaffiliated. That's a powerful voting block. SA

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The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column for so long that if it were charged it would be tried as an adult. He also hosts the *Scientific American* podcast Science Talk.

Phoning It In

Distracted walking is the new hip reason for an ER trip

Back in 2010, in this space, I described my near run-in with he whom I dubbed "Scooter Boy." This yutz was driving down a busy road in Florida on, you guessed it, a scooter, the handlebars of which were unsullied by human contact. Because both of his hands were busy texting on a smartphone. To add insult to his inevitable injury, earbuds blocked up the auditory appendages on the sides of his helmetless head, to further insulate him from sensory awareness of his dangerous reality.

I was recently reminded of the distracted adventures of Scooter Boy when I saw a study that showed just how far we have come as a culture in our attempts to be preoccupied as we move through space. The research paper in question found a whopping recent increase in emergency room visits for injuries sustained because people were fiddling with a cell phone while—let's not tiptoe around the issue here—walking.

The authors of the report, "Pedestrian Injuries due to Mobile Phone Use in Public Places," used data from 100 U.S. hospitals to approximate the numbers for the entire nation. In 2004 an estimated 559 people had, in one scenario, whacked themselves hard enough on a telephone pole to need emergency room treatment. By 2010 the number of walkers who had to finish that last text in the ER had likely topped 1,500, according to the study, which appeared in the journal *Accident Analysis & Prevention*.

During the same time period, the total numbers of pedestrians who wound up in emergency rooms actually decreased. Cell phone–related pedestrian injuries are thus doing yeoman's work in keeping our ER docs in business.

Now sit down while you read this next part, especially if you're reading on a smartphone: it turns out that males between the ages of 16 and 25 were the group most prone to the injuries discussed in the report. I was once in that cohort, with all its negative health sequelae. Fortunately, I was cured (of the age part) by that great healer, time. Now I text in a recliner, as nature intended.

In fairness, young people whose brains have not yet completely congealed merely represent a plurality of smartphone-pedestrian injuries. I know of a prominent scientist—a really big cheese, a whole wheel of Gorgonzola—who tumbled down the stairs while screwing around on a phone and wound up hospitalized. This person (who will remain nameless to protect my sources) knows all too well that whether you are using an iPhone, a Galaxy, a Droid or a Jitterbug, force equals mass times acceleration.

Experts expect the injury toll related to phones to keep rising. "If current trends continue, I wouldn't be surprised if the number of injuries to pedestrians caused by cell phones doubles again between 2010 and 2015," said Ohio State University's Jack Nasar, a co-author of the study, in a press release. And he thinks that the official numbers are probably underestimates of the true injury rate because not everyone who gets hurt goes to the hospital and not everyone who goes admits the real reason that they walked into a fire hydrant.

Moreover, the report tracked only pedestrian incidents outside the home. So it wouldn't count if you wound up in the ER because you were playing Angry Birds in your living room and tumbled over the ottoman Dick Van Dyke–style. (If that reference is about as relevant to you as the Ottoman Empire, it's on YouTube. For the Ottoman Empire, see Wikipedia.)

So what can we do to mitigate the risks posed by these insidious devices? Nasar thinks we have to change our societal attitudes about phone use. "Parents already teach their children to look both ways when crossing the street," he said. "They should also teach them to put away their cell phone when walking, particularly when crossing a street."

Or, as an acknowledgment of how we use the gadgets, maybe we could just stop calling them *smart*phones. SA

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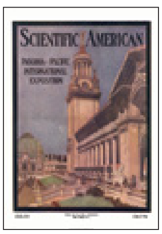
Illustration by Matt Collins

December 1963

Quasars Found

"Early this year astronomers discovered that five celestial objects, previously regarded as being faint and somewhat unusual stars in our galaxy, are perhaps the most bizarre and puzzling objects ever observed through a telescope. Not faint stars at all, they are extremely powerful sources of radio noise and, according to new estimates of their light output, are perhaps the brightest objects in the universe. The dramatic recognition of these unusual objects was the result of a fruitful collaboration between radio and optical astronomers. The former provided precise positions of five radio sources, which were then identified with starlike objects on photographic plates made at the Mount Wilson and Palomar Observatories. In recognition of their small size, and for lack of a better name, they are called quasi-stellar radio sources."



December 1913

Piltdown Hoax in the U.S.

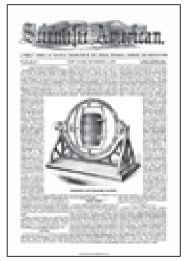
"If the very widespread publicity on the part of the press is a fairly accurate measure of general interest in a subject, then the prominence and space accorded to recent interviews with me on the theme of prehistoric man indicate something more than mere curiosity on the part of the public. It has also been very interesting to me to observe that nearly all of the papers in different parts of the country that have mentioned the subject have given special prominence to the statement of the great age of man on the earth. That is really one of the vital aspects of the whole problem of man's origin. Recent discoveries have made it quite plain that the human race has been in existence for a much longer time than has generally been supposed by the majority of scientific men. —Dr. J. Leon Williams"

Piltdown Man was supposedly an early human fossil found in England in 1912. The find was definitively proved a hoax in 1953. Dr. Williams, a prosthodontist by trade, was an enthusiastic, but gullible, amateur anthropologist. As early as November 1913, a letter in Nature *(now a sister publication of* Scientific American*), by a skeptical David Waterston of King's College London, correctly identified the skull as modern human and the jaw as being from an ape.*

Water for a City

"The new Los Angeles Aqueduct is designed to bring 265 million gallons of water daily over a distance of 234 miles from the Sierras to Los Angeles. This new aqueduct was dedicated and opened to use on November 5th, and on our front page of this week's issue we present a view taken at the moment when the gates were opened to start the flow of water down the cascade formed below the exit of the tunnel through the Santa Susana Range, 25 miles northwest of the city of Los Angeles. This cascade fulfills a double function—it was designed partly on esthetic grounds, but also for the purpose of assisting in the purification of the water by aeration."

For a photograph album of images from 1913 on engineering and water, see www.ScientificAmerican.com/dec2013/water-1913



December 1863

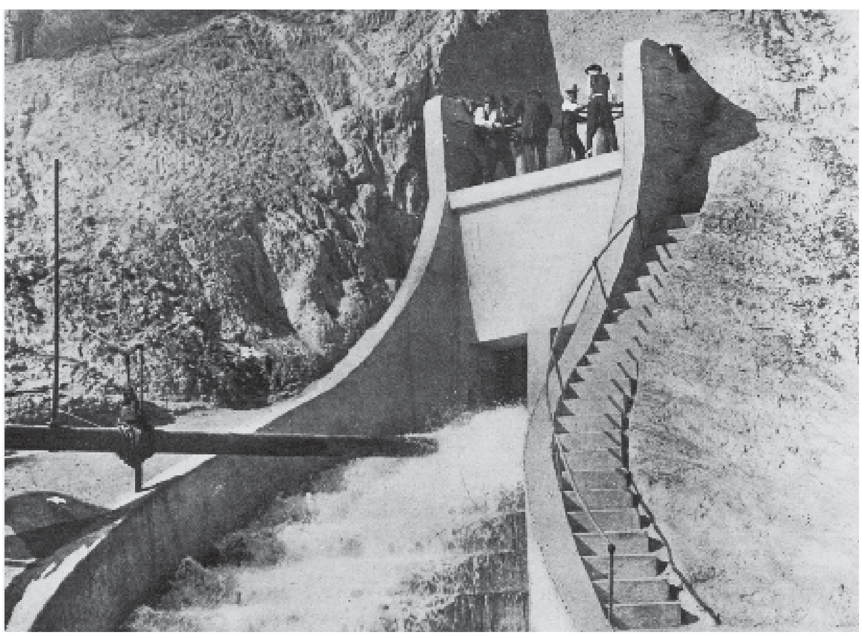
The First Recording Device

"Some months ago, M. Scott [Édouard-Léon Scott de Martinville], well known among the savants of Paris, exhibited experiments of a very interesting character, in the art of fixing [that is, capturing] sounds. The same species of natural means so successfully employed in photography with reference to form, namely, the aerial undulations [sound waves] of which sounds consist, are, by the construction of the *phonograph,* made ingeniously to subserve the same intricate purposes in view. Yet a serious difficulty seems to obstruct a re-translation of this somewhat indefinite language into the regular and fixed signs for the verbal sounds which produced it."

This device, now called the "phonautograph," could only register sounds, not play them back.

Medical Advice

"The latest remedy for sea-sickness is ice. We imagine a better one is not to go to sea."



WATER FOR LOS ANGELES: The new aqueduct is opened for the first time, 1913

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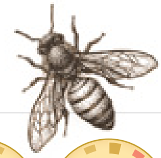
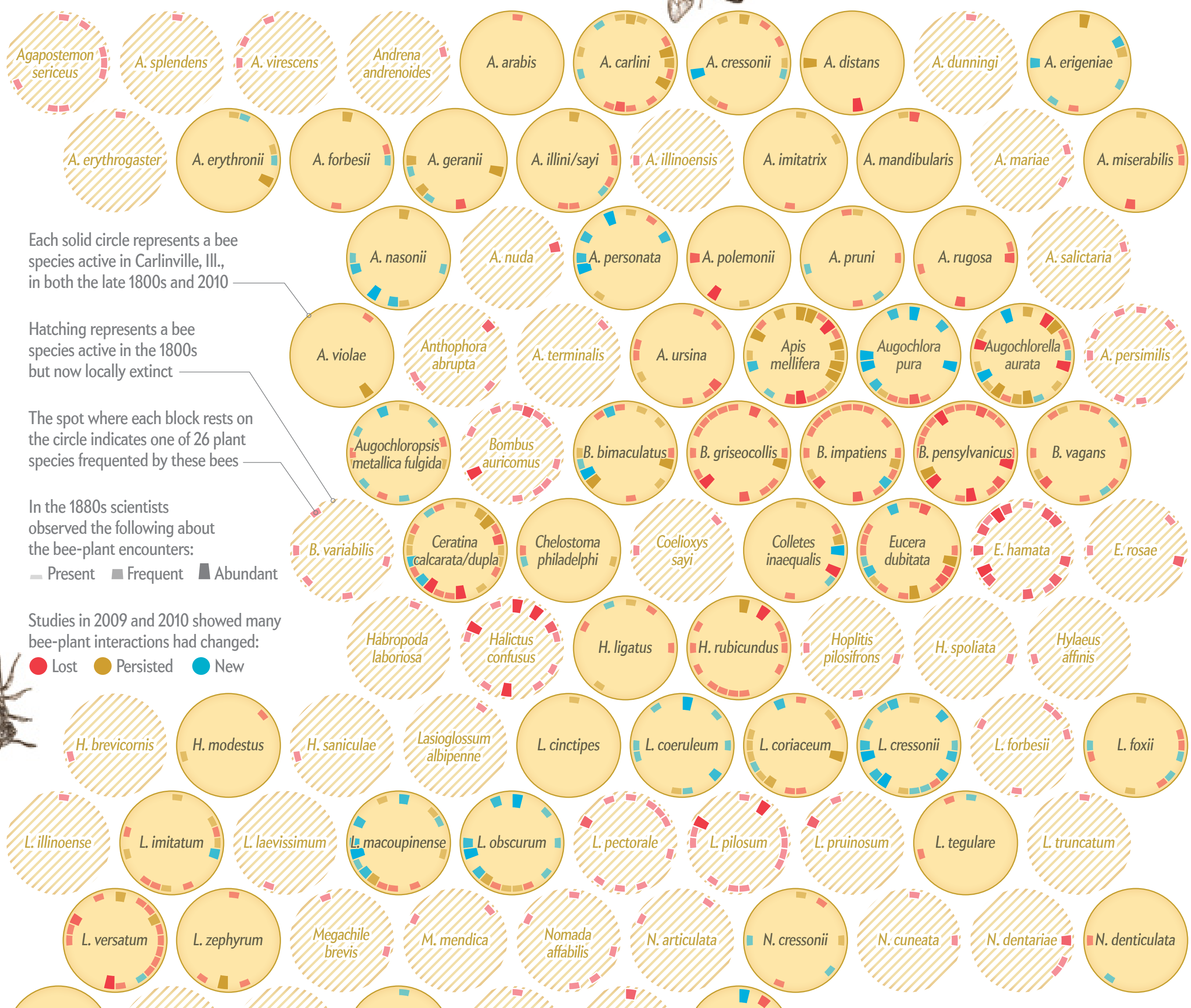


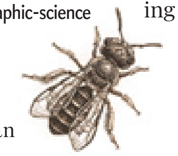


Where the Wild Bees Are

Croplands and climate change displace native bees

Farmers have always depended on both honeybees and native bees to pollinate crops. As honeybees die en masse, wild bees are needed more than ever—but they, too, are disappearing. In the late 1800s naturalist Charles Robertson traveled around Carlinville, Ill., by horse and buggy, meticulously recording which bees visited which flowers. In 2009 and 2010 ecologist Laura A. Burkle, now at Montana State University, and her colleagues repeated some of Robertson's studies. The dense network of plant-pollinator relationships Robertson originally documented had deteriorated. Less than half as many interactions occurred in 2009 and 2010 as in the 1800s. Ironically, ever expanding croplands have most likely killed off local populations of native bees by depriving them of natural habitat and exposing them to toxic pesticides. And climate change has thrown off the bees' timing by shifting bloom cycles. But life is resilient: in 121 instances, Burkle observed bees attending flowers they had not pollinated in the past. *—Ferris Jabr*

SCIENTIFIC AMERICAN ONLINE
Read more about native bees at ScientificAmerican.com/dec2013/graphic-science

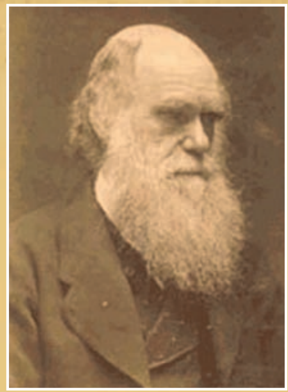


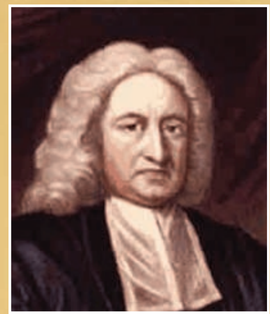
SOURCE: "PLANT-POLLINATOR INTERACTIONS OVER 120 YEARS: LOSS OF SPECIES, CO-OCCURRENCE, AND FUNCTION," BY LAURA A. BURKLE, JOHN C. MARLIN AND TIFFANY M. KNIGHT, IN *SCIENCE*, VOL. 339; MARCH 29, 2013

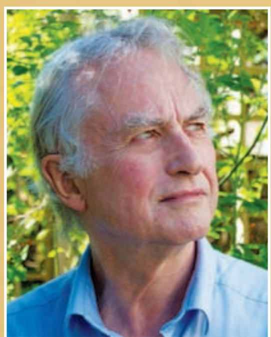
Graphic by Moritz Stefaner, Illustration by Jillian Walters (bees)

What do these scientists have in common?

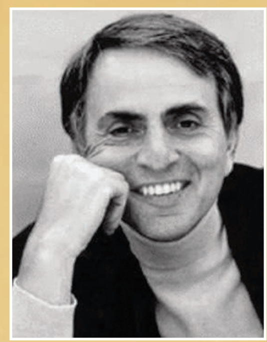

Marie Curie


Charles Darwin


Edmund Halley


Richard Dawkins

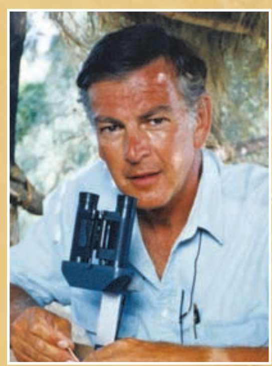

Steven Pinker
Honorary President of the
Freedom From Religion Foundation


Carl Sagan


Luther Burbank

They have rejected the supernatural.*

They have worked to improve *this* world.


Donald C. Johanson

* 93% of elite scientists reject belief in a personal god or human immortality. *(Nature, Vol. 394, No. 669, 1998)*

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